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Vol. XIV October, 1928 No. 4

PRE-CONVENTION ISSUE

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RAY T. BAYLESS, *Editor*

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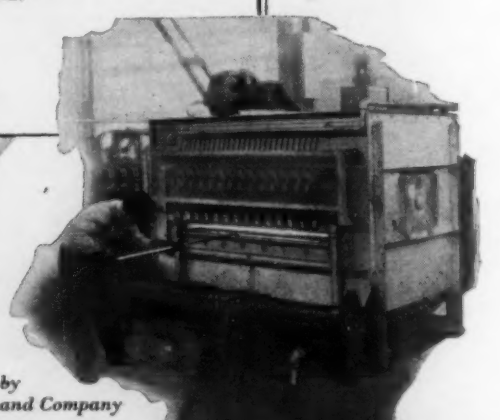

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VOL. XIV OCTOBER, 1928 NO. 4

NOTES ON THE RELATION OF DESIGN TO HEAT TREATMENT

By Frank R. Palmer

Abstract

This paper sets forth the fundamental principles of design as they affect heat treatment and subsequently—the serviceability of finished parts.

A tool or machine part is properly designed, from the standpoint of heat treatment, when the entire piece may be heated and cooled at approximately the same rate, thus eliminating insofar as possible internal strains which develop during quenching, due to wide changes of temperature. The correct shaping and balancing of the weight of sections is discussed at some length and several interesting examples of good and poor design are presented.

DESIGN bears in many ways upon the serviceability of a tool or machine part, and unsatisfactory performance may frequently be traced directly to faulty design. This paper deals with only one phase of the subject. A tool may refuse to cut because it is improperly relieved, or a cam may fail to function, because its curvature is wrong. These are errors in design and yet they have no bearing at all on our present subject. This paper is concerned with design only as it affects the heat treating operation—and through the heat treatment, the serviceability of the finished parts.

Tools and parts are sometimes designed in such form that it is almost impossible to harden them without cracking or distorting

The author, Frank R. Palmer, a member of the society, is assistant to the President, Carpenter Steel Co., Reading, Pa. Manuscript received July 11, 1928.

beyond usefulness; others become so strained in heat treating that early failure in service is inevitable. Frequently the designer can relieve a condition of this sort, and it is the purpose of this discussion to bring about a better mutual understanding between the designer and the steel treater.

The fundamental principles of good design from a heat treatment standpoint are quite simple. Heat treated steel has a certain strength depending upon the analysis of the steel, the quality of the metal, and the heat treatment which it has received.

When subjected to a combination of forces beyond its ultimate strength, the steel cracks or fails. So much is obvious. There are two types of force combining to break the steel:

1. The internal strains set up during fabrication and heat treatment of the part
2. The external forces of service.

Sometimes the internal strains alone exceed the strength of the metal and the part cracks in hardening. Again, the internal strains may equal ninety per cent or more of the total strength, in which case failure will develop in service under relatively light loads. It therefore appears that the useful strength of a part is complementary to the extent of the internal strains.

Internal strains arise from many causes, but the most serious, by far, are those developed during quenching, by reason of differential cooling. This differential cooling, (or more accurately "temperature gradient"), is very largely a function of the size and shape of the piece being quenched—in other words, the *design*. Here, then, is the relation of design to heat treatment, and the basic principle of successful design is to plan shapes which will keep the temperature gradient, throughout a piece, at a minimum during quenching.

What do we mean by a temperature gradient? Most broadly defined a *gradient* is a "rate of change", and a *temperature gradient* is a "rate of change of temperature".

Fig. 1 may be taken to represent a steel cube interrupted during the process of quenching. Consider the points A and B separated by a distance "d". If, at any given instant during the quench, A is 700 degrees Fahr. and B is 300 degrees Fahr. and "d" equals 1 inch, the temperature gradient between these two

points is 400 degrees Fahr. per inch. If the points are only ½ inch apart, the gradient is said to be twice as steep.

We know instinctively that certain shapes are almost impossible to harden because of the abruptness in the change of section. On the other hand, we recognize a certain latitude in design when using an oil hardening or air hardening steel. All things being equal, the gradient between A and B, in Fig. 1, will be much less in oil than in water, and will be less in air than in oil. Thus,

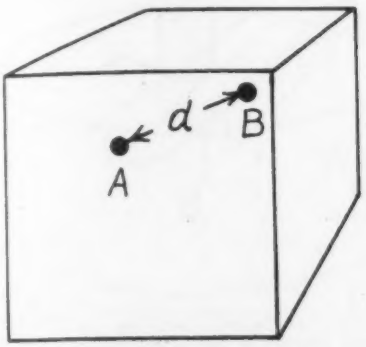

Fig. 1 — Sketch Representing Steel Cube, Illustrating What is Meant by Temperature Gradient "if the Distance Between Points A and B is 1 Inch and the Difference in Temperature Between Point A and Point B is 400 Degrees Fahr. the Temperature Gradient Between the Two Points is 400 Degrees Fahr. per Inch."

Fig. 2—Sketch Showing Steel Tapered Pin. It is Obvious that the Point of the Pin Will Cool Faster Than the Heavier Section.

we introduce the idea that a certain design may be perfectly safe for one kind of steel, or one type of coolant, and unsafe for another.

Errors in design reach farther than merely affecting the internal strains during hardening. A sharp angle serves to greatly concentrate the stresses of service, and the design of the part may be entirely responsible for concentrating the service stresses at a point already weakened by internal strains produced during hardening. This latter phase is outside the scope of this paper, but is of collateral importance because concentration of service stresses frequently parallels concentration of heat treating strains, and are frequently cause and cured by the same combination of circumstances.

Reducing all the above to a single statement, a part is properly designed, from a standpoint of heat treatment, when the entire

piece may be heated and cooled at approximately the same rate during the heat treating operation. Perfection in this regard is unattainable because even on a sphere, the surface cools more rapidly than the interior. The designer should, however, attempt to so shape his parts that they will heat and cool as uniformly as possible. The greater the temperature difference be-

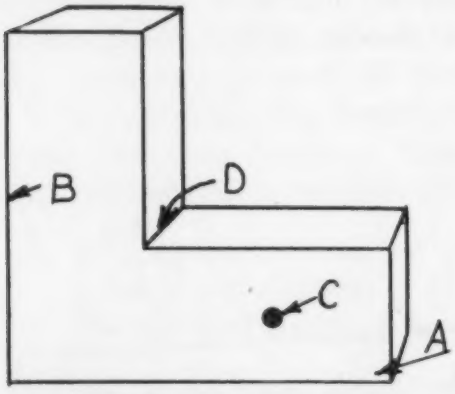

Fig. 3—Sketch Showing a Piece of Steel, Illustrating the Manner in Which the Different Portions of the Piece Will Cool During Quenching As Discussed in the Text.

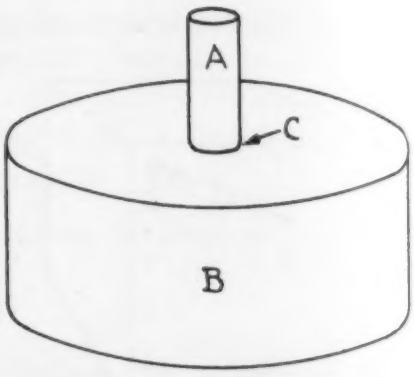

Fig. 4—Sketch Showing a Piece of Steel Having a Light Section and a Very Heavy Section. It Would be Practically Impossible to Quench this Piece of Steel from Proper Hardening Temperature Without Causing a Crack at Point C.

tween any two points on a given part during quenching, and the closer these two point are together, the greater will be the internal strain and therefore the poorer the design.

There are really not many possibilities for subdividing this main thought. Almost every failure due to improper design can be attributed directly to a violation of the fundamental principle. Some general cases may however be considered.

Effect of Shape on Cooling Speed

When a piece of steel is removed from the hardening furnace preparatory to quenching, it is presumably at a uniform temperature. As soon as quenching begins, the temperature is different in almost every part of the section. This difference in temperature is due to two conditions. In the first place, the heat capacity or heat storage may be greater in one part of the section than in another—due simply to the fact that there is more metal in one part than in another. This is illustrated very simply by a tapered pin, as shown in Fig. 2. Obviously, the point of this pin will cool

faster than the heavy section, because there is less heat to be dissipated per square inch of cooling surface.

Also, the rate of cooling is affected by the shape of the surface. Fig. 3 illustrates a piece which is quite uniform in cross section, but which will not cool uniformly. The protruding corners, such as A, are cooled from three sides so that the extreme corner

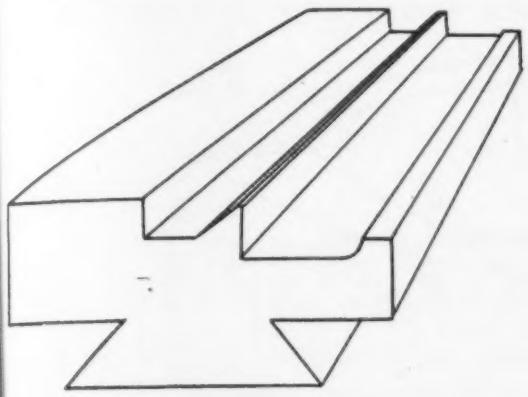

Fig. 5

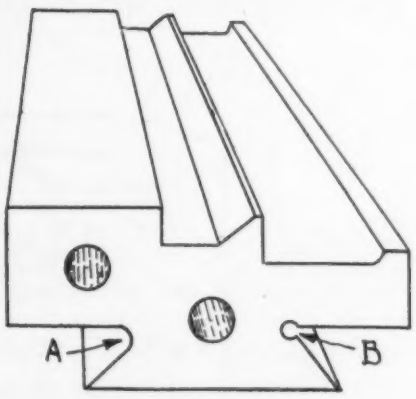

Fig. 6

Figs. 5 and 6—Sketch Showing an Under Cutting Form Tool, One of Which has a Heavy and Light Section and the Other of Which has a Uniform Section. Fig. 5 Shows Incorrect Design and Fig. 6 Shows Correct Design.

is giving off heat through seven times as great an area as it is receiving heat. An edge, such as B, is cooled from two sides and is giving off heat through three times as great an area as it is receiving heat. A point on the flat side, such as C, receives heat from one side and delivers it from the other, and the cooling area and the heating area are approximately equal.

At a reentrant angle, such as D, heat is being supplied to the surface through three times as great an area as it is being dispelled, and this point will naturally cool last. Sharp reentrant angles are always objectionable from the standpoint of design. It is impossible to get uniform cooling during the quench in the immediate neighborhood of a sharp angle. Vapor pockets will frequently form in the corners and produce an actual soft spot. Even if no soft spot is formed, the rate of cooling at the point of the angle is bound to be slow, because the corner is so inaccessible to the coolant. Differential cooling thus sets up heavy internal strains at a point which is almost certain to receive concentrated stresses in service.

It will be seen from the above that it is possible for one part

of a section as shown in Fig. 3 to cool many times faster than another part.

If we have a section as shown in Fig. 4, we have a combination of the conditions given in both previous illustrations. The heat capacity of the body "B" is much greater than the projection A, and we have a sharp reentrant angle at point C. It would be practically impossible to harden such a shape in water without

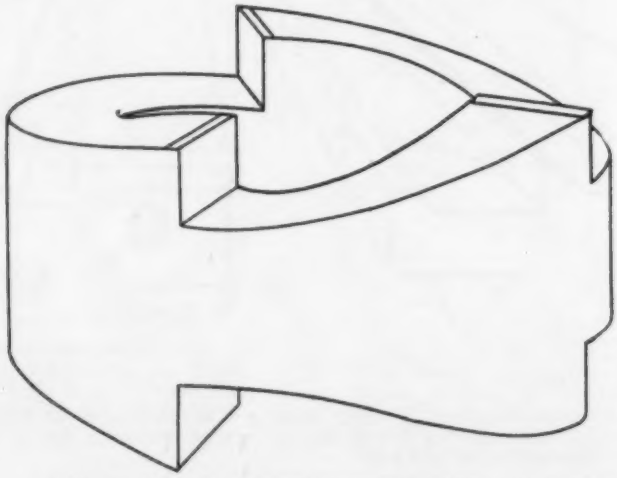

Fig. 7—Sketch Showing Improper Design in a Double-Ended Side-Mill or Spot Facer. It is Almost Certain that the Tool will Crack on Quenching from Hardening Temperature, at the Junction Between the Light and Heavy Sections.

cracking at the sharp corner. Even oil quenching would be doubtful on a piece of these proportions, and only by cooling in air could we expect to keep the thermal gradients down to a safe point. A few practical illustrations are given in Figs. 5 and 6 to illustrate the above principles.

Fig. 5 illustrates an under-cutting form-tool. It will be noticed that the cross section of this tool is make up of heavy and light sections joined together with sharp reentrant angles. A tool of this shape would be extremely hazardous to harden either in a water-hardening tool steel or a high speed steel.

A corrected design for the above tool is illustrated in Fig. 6. Holes have been drilled through the two heaviest sections, and thus the weight of the metal has been fairly well balanced throughout the cross section of the tool. The sharp angles on the cutting edge cannot be eliminated because they are a part of the form of the tool. Two suggested treatments are shown for the angle at the base of the dovetail. The best treatment is shown at A, where a

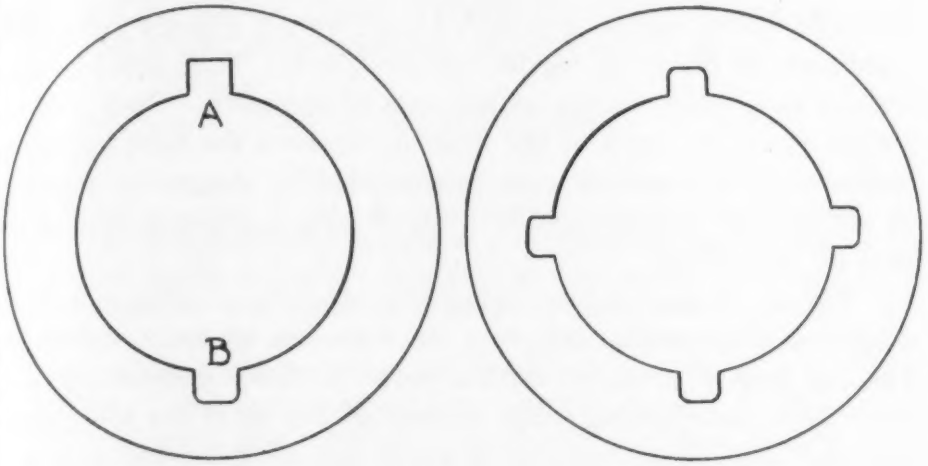

Fig. 8 Fig. 9

Fig. 8—Sketch Showing Correct and Incorrect Type of Key-Ways. Key-Way at A has Sharp Corners and is Basically of Improper Design. Key-Way at B Has Rounded Corners and is Fundamentally of Correct Design. Fig. 9—Sketch Showing the Method of Balancing Stresses in the Use of Key-Ways Cut 90 Degrees Apart, thus Equalizing the Quenching Stresses.

generous fillet is provided. An alternative is shown at B, where the corner has been under-cut to provide a radius and still give the effect of a sharp corner. From a standpoint of quenching

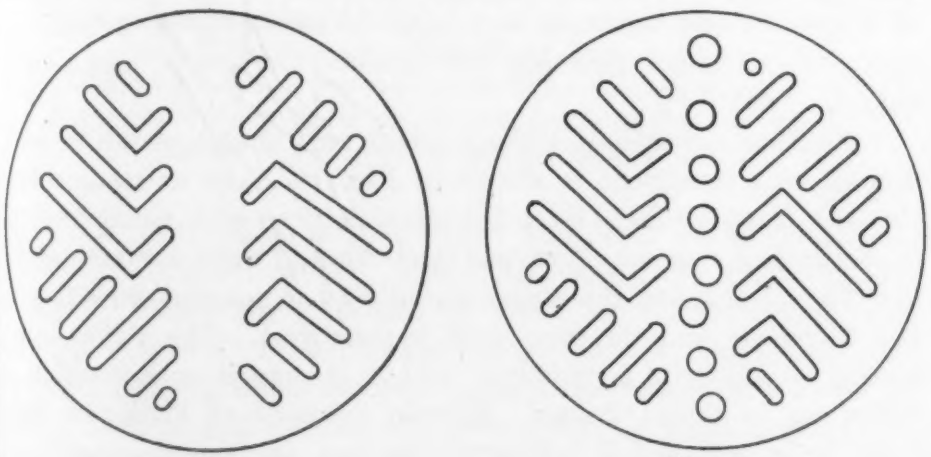

Fig. 10 Fig. 11

Fig. 10—Sketch Showing a Blanking Die Having a Heavier Center Rib Than the Surrounding Areas, thus often Resulting in Warping During Quenching. Fig. 11—Sketch Showing a Similar Die Having Holes Drilled in the Middle Rib to Equalize the Amount of Metal Throughout the Die, thus Obviating Warpage Difficulties.

strains, the under-cut form at B has little to recommend it, but it does have the advantage that there is no absolutely sharp corner in which the stresses can accumulate.

Fig. 7 illustrates a case of improper design in a double ended side-mill or spot-facer. Each side of this tool has three teeth with

the teeth placed opposite to each other; we get a badly unbalanced condition in the cross section of the piece. This is made more serious by a sharp corner at the base of the teeth. Such a tool is almost certain to crack at the junction between the light and heavy sections. This condition may be corrected by staggering the teeth on opposite sides of the tool and introducing a generous fillet at the base of each tooth.

Fig. 8 illustrates two principles of design. This is a ring-shaped section containing two key-ways on opposite diameters. The key-way A is shown with absolutely sharp corners. This is never good design, and, while millions of key-ways are being made and used with sharp corners, this does not alter the fact that it is poor design, and every effort should be bent toward making standard a round cornered key-way such as is shown at B.

The second interesting point about this ring is that when it is quenched it will not stay round. The section of the ring is weakened through the two key-ways, and almost invariably the ring will become oval. This condition may be corrected by cutting in two more key-ways at 90 degrees to the first two, as is illustrated in Fig. 9. These key-ways may be of no use but they certainly do no harm, and their presence will balance the section and keep it round.

Another example of a shape which will almost certainly warp during heat treatment is shown in Fig. 10. Let us assume that this is a blanking die. Even though this piece were made from an oil-hardening, non-changing, tool steel it would warp during quenching. The rib through the center would tend to prevent shrinkage in this direction, and the die would become oval. This figure is intended to illustrate a principle, and it is surprising how often it comes up in actual design. Certain portions of a die are held rigid by a web, while adjacent portions are unsupported, and warpage or distortion occurs during hardening which cannot be avoided without resorting to an air-hardening steel. Frequently it is possible to break the back of such a rib by drilling holes, as illustrated in Fig. 11. Holes drilled for such purposes should always be of such size and so located as to help balance the section, rather than to unbalance it. Our success in preventing warpage, and other forms of internal strain, will be directly proportional to our success in balancing the weight of the sections and producing uniform cooling conditions.

EFFECT OF QUENCHING TEMPERATURE CHANGE ON THE PROPERTIES OF QUENCHED STEEL

By O. W. McMullan

Abstract

A comparison of hardness results obtained by different hardness testers is shown plotted against Vickers hardness as a standard. Curves showing the hardness obtained on the case and core of carburized nickel-molybdenum and plain carbon steels are presented; also the effect of low temperature draws on the same. Medium carbon alloy steels and plain carbon steels were treated in different sizes, and hardness results obtained at the surface and the center. These latter were given both a drastic quench and a milder quench to duplicate commercial conditions. A high carbon tool steel was also treated. Tensile and impact results were obtained on all but the tool steel from a few selected temperatures showing characteristic properties. Important results noted are that maximum surface hardness on high carbon steels is obtained at low quenching temperatures; that maximum center hardness of quenched steel occurs at a much higher temperature along with a more or less sudden increase in grain size; and the marked effect of a low temperature draw on the hardness and other physical properties of the core of S.A.E. 1020 steel.

A FEW years ago, difficulty was met with at this plant in hardening automobile front axles made from a certain heat of S.A.E. 1035 steel, quenched in water at 1550 degrees Fahr. After making a number of experiments, it was found that such parts not only came harder at a lower temperature, but hardened more uniformly and deeper, also giving finer grained and tougher fractures. The same results have been repeatedly confirmed on various parts from steel of that composition since that time. It has also been found on carburized parts, particularly on large parts such as worms for worm driven truck and bus rear axles, made from S.A.E. 4620 or 3120 where a high scleroscope limit was required, that a quenching temperature of 1380-1390 degrees Fahr.

The author, O. W. McMullan, a member of the society, is on the metallurgical staff of the Timken-Detroit Axle Co., Detroit. Manuscript received August 13, 1928.

gave 5 to 10 points higher scleroscope hardness than 1410-1420 degrees Fahr. These results obtained in a commercial way led to a more detailed investigation which is the subject of this paper.

Methods of Hardness Testing

Comparative results obtained from the use of the Vickers, Brinell, Rockwell, and scleroscope hardness instruments show that

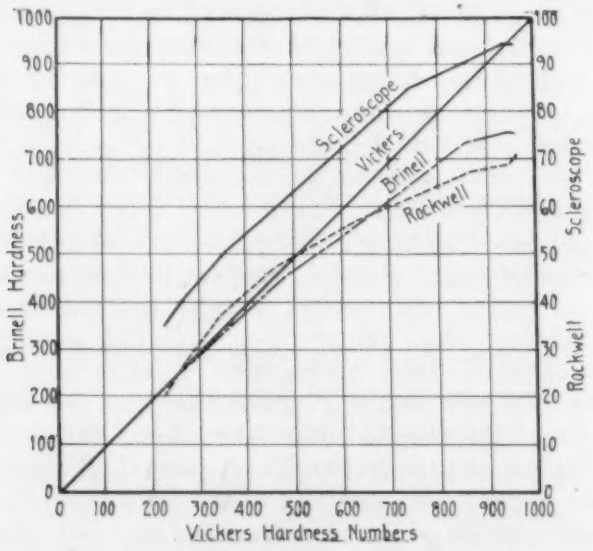

Fig. 1—Curves Showing Comparative Values of Vickers, Brinell, Rockwell, and Scleroscope Hardness Obtained on Quenched and Tempered Tool Steel Using Vickers Hardness as a Standard.

the Vickers machine is more sensitive to small hardness changes and gives a more uniform curve at the higher hardness values than the other methods. For this reason the Vickers[1] was used on the carburized samples as well as on some of the others.

Fig. 1 shows comparative hardness curves obtained from bars of quenched and tempered carbon tool steel plotted against Vickers results as a standard.

Steels

A plain carbon and alloy carburizing steel, plain carbon and alloy medium carbon steels, and a high carbon tool steel were used in the tests. They were quenched in oil or water according to the usual practice for the particular composition. The S.A.E. 1035 steel included heats from three different steel companies. See Table I for the composition of the steels.

[1] "Some Notes on the Use of a Diamond Pyramid for Hardness Testing," Smith and Sandland, *Journal*, Iron and Steel Institute, 1925, No. 1, Vol. CXL, page 285.

Fig. 2 shows the Vickers hardness results obtained on the case and core of carburized steel A, (S.A.E. 4615) by quenching in water and also after tempering at the temperatures given on the chart. The samples used were tapered roller bearing rolls ap-

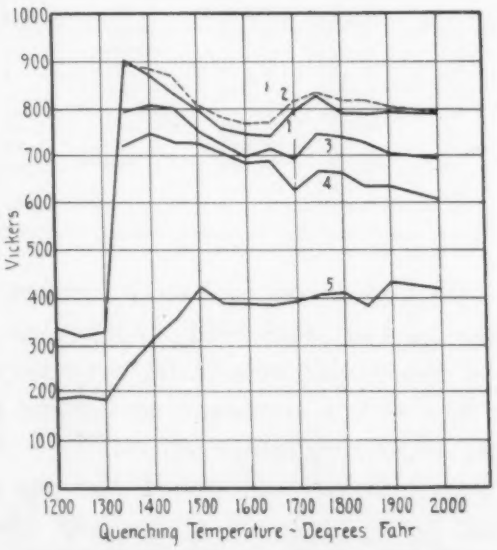

Fig. 2—Vickers Hardness of Carburized and Water-Quenched S.A.E. 4615 Steel, A. Curve (1) Case as Quenched; Curve (2) Tempered 1 Hour at 212 Degrees Fahr; Curve (3) at 350 Degrees Fahr.; Curve (4) at 500 Degrees Fahr; and Curve (5) on the Core After the 500-Degree Fahr. Tempering Operation.

proximately $\frac{11}{16}$ inch at their mean diameter. They were gas carburized to give the following carbon content in the case when samples were turned off as below:

Cut	Per Cent Carbon
1st —0.005 inch on radius.....	Discarded
2nd —0.010 inch on radius.....	1.02
3rd —0.010 inch on radius.....	0.98
4th —0.010 inch on radius.....	0.84
5th —0.010 inch on radius.....	0.81
6th —0.010 inch on radius.....	0.73

The double treated samples were quenched in oil from 1550 degrees Fahr. and then given a water quench similar to the single treated samples, 1500 degrees Fahr. being the highest temperature quenched from on the second heat. All samples were held in a small pair of tongs and agitated in clear cold water at a temperature of 45 to 50 degrees Fahr. They were heated in an electric muffle furnace, except those above 1900 degrees Fahr which were

Table I
Composition of Steels Used

Key	Type	C	Mn	P	S	Cr	Ni	Mo
A	4615	0.194	0.57	.....	.....	....	1.81	0.22
B	1020	0.17	0.37	0.022	0.040	....	....	....
C	1035	0.35	0.62	0.016	0.031	....	....	....
D	1035	0.35	0.63	0.021	0.029	....	....	....
E	1035	0.35	0.53	0.020	0.035	....	....	....
F	1035	0.33	0.65	0.020	0.045	....	....	....
G	Tool	1.25	0.24	.....	.....	....	....	....
H	3240	0.40	0.56	0.021	0.022	1.08	1.65	....
I	3240	0.40	0.53	0.019	0.020	1.02	1.68	....
J	4615	0.155	0.58	0.020	0.016	....	1.69	0.21
K	1035	0.39	0.70	.....	.....	....	....	....
L	3240	0.41	0.49	.....	.....	1.00	1.75	....

heated in an oil-fired high speed tool steel furnace. Samples were put in the furnace at heat and held 20 minutes. The hardness values obtained by the double treatment were very similar to the single treatment but with a tendency to become softer than the latter at the higher tempering temperatures.

All samples were polished and etched in 4 per cent nitric acid. It was found that those quenched at the low temperatures and having the highest hardness were most easily darkened in the case by the etching acid, giving a dark greenish-gray appearance on etching 10 to 15 seconds, those at the higher temperatures becoming a light brown. After a 5-second etch the harder samples were colored slightly while the softer ones retained a white martensitic appearance. The highest magnification used was 500 diameters. A higher magnification would possibly show that the etching shades were dependent upon the amount of retained austenite.

All samples, both single and double treated, quenched at 1650 degrees Fahr. or below, were fine-grained in both the case and core; the 1650 degrees Fahr. samples being slightly coarser than those quenched at 1350 degrees Fahr. At 1700 degrees Fahr. there was a slight coarsening in the gradation zone of the case which was still further increased at 1750 degrees Fahr. At 1800 degrees Fahr. there was considerable increase in the grain size of the outer part of the case and still more at 1850 degrees Fahr., also the core showed a few coarse crystals. At 1900 degrees Fahr. and above, both the case and the core were very coarse-grained.

None of the double treated samples showed any cracks in the case. Of the single treated samples only one below 1650 degrees Fahr. (that at 1500 degrees Fahr) was cracked, while all of those

quenched at 1650 degrees Fahr. or above were cracked, some of them quite badly.

The curve in Fig. 2 shows that the hardness increased slightly after tempering in boiling water for one hour. The microscopic examination showed similar structures to those before tempering.

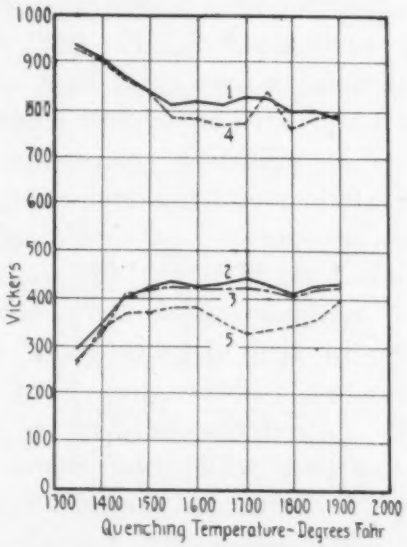

Fig. 3—Comparative Hardness of Carburized and Water and Oil-Hardened S.A.E. 4615 Steel A. Curve (1) on the Case of the Water-Quenched Samples as Quenched; Curve (2) Core of Water Quench as Quenched; Curve (3) Core of Water Quench After 500-Degree Fahr. Temper; Curve (4) Case of Oil Quench as Quenched; and Curve (5) Core of Oil Quench as Quenched.

It is thought that a possible explanation of the increased hardness is that it was due to age hardening as obtained by Sykes and Jeffries on tool steel[2]. When tempered at 350 degrees Fahr. the hardness fell off and the samples showed increasing amounts of troostite with increasing tempering temperatures.

Comparative results for oil and water quenching are shown in Fig. 3. The samples were taken from carburized 5/8-inch diameter, S.A.E. 4615 bar stock. The carburizing was done in solid carburizing material in a batch furnace. The case was not as deep, but of higher carbon content on the outside than the previous set of samples. The results are averages of three readings on each of three samples at intervals of 50 degrees Fahr. in quench-

[2] "On the Constitution and Properties of Hardened Steel," TRANSACTIONS, American Society for Steel Treating. Vol. XII, No. 6, December 1927, page 871.

ing temperatures. It is quite probable that a greater difference in hardness between oil and water quenching would be obtained on larger pieces.

It might be stated at this time these results obtained in the laboratory have been fully confirmed in commercial practice in the heat treating department. Large worms for truck and bus drives made from carburized S.A.E. 4620 and 3120 are good examples. Some of these worms are 4 to 5 inches in diameter in the threaded portion and have an overall length of more than two feet. A hardness of 85 minimum scleroscope is required on the side of the threads after quenching and tempering and difficulty has frequently been encountered in obtaining it. At times such worms, when quenched at 1410 to 1420 degrees Fahr., or even 1400 degrees Fahr., would not come up to this limit while, when quenched from 1380 to 1390 degrees Fahr. would readily pass and were more than 80 (scleroscope) hard after grinding off 0.010 to 0.015 inch. (A scleroscope limit of 80 is allowed after grinding.) In connection with these same worms, quenching in warm water or oil generally produced no better or even poorer results, particularly so with the oil. Brine or 10 per cent sodium hydroxide also gave poorer results than cold water, probably due to the greater amount of retained austenite. Tempering at any temperature would not make these caustic soda quenched worms as hard as those quenched in cold water. One plausible explanation for this is that a greater amount of martensite is produced directly from the quench in cold water and that the decomposition product of retained austenite, as produced by the caustic soda quench, is troostite and not martensite.

It was thought that the high hardness of the samples at the low temperature was a result of passing through the critical range at the maximum cooling rate obtained when first immersing the piece. This maximum cooling rate on first immersing would occur above the critical range at the higher temperatures and the excess heat would retard the cooling rate at the time of passing through the critical range. This, at the most, was proved to be only a partial explanation by the following experiments. Samples of the above mentioned 4615 rollers were used; some were quenched in water from the low temperature (1375 degrees Fahr.), giving the highest hardness; some from the temperature (1625 degrees Fahr.),

giving the lowest hardness; some heated at 1625 degrees Fahr., cooled in the furnace to 1375 degrees Fahr., and quenched; and some given a double quench.

Treatment	Vickers Hardness
1625 degrees Fahr., Water-Quenched	753
1625 degrees Fahr., Cooled in furnace to 1375 degrees Fahr., and water-quenched	808
1375 degrees Fahr., Water-Quenched	891
1625 degrees Fahr., Water-Quenched and reheated to 1375 degrees Fahr. and water-quenched	882

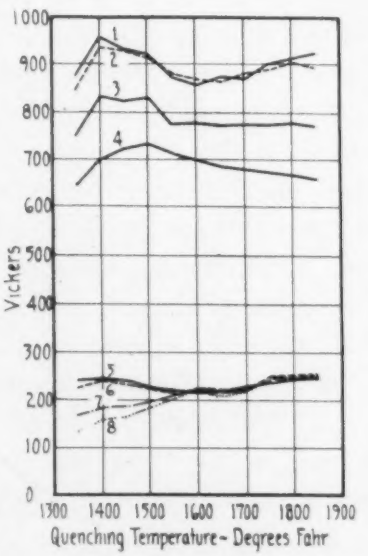

Fig. 4 — Vickers Hardness of Carburized and Water-Quenched S.A.E. 1020 Steel, B. Curve (1) Case, No Temper; Curve (2) Case, 212-Degree Fahr. Temper; Curve (3) Case, 350-Degree Fahr. Temper; Curve (4) Case, 500-Degree Fahr. Temper; Curve (5) Core, No Temper; Curve (6) Core, 212-Degree Fahr. Temper; Curve (7) Core, 350-Degree Fahr. Temper; Curve (8) Core, 500-Degree Fahr. Temper.

Only part of the hardness was recovered by lowering the temperature before quenching, the loss probably being due to increased grain size and other structural changes. The double treatment had but little effect on the hardness, showing that the carbide in excess of eutectoid composition affected the hardness the same whether in or out of solution. (The carbon content, however, was only slightly over 1 per cent.)

The curves obtained with steel B (S.A.E. 1020) carburized

and hardened, were similar in general form to those from steel A. The maximum hardness obtained with B was greater but a more rapid falling off in hardness with increasing tempering temperatures was obtained as shown in Fig. 4.

Interesting results were obtained on the core of this steel on those samples quenched below the upper critical range. The various tempering temperatures softened these samples considerably while those quenched above the critical range remained practically unchanged. The core of the sample quenched at 1350 degrees Fahr. consisted almost entirely of ferrite and martensite, the former pearlite grains, with practically no increase in size, were transformed to martensite except for narrow borders of troostite on some of them. With increase in temperature these martensite areas became larger and the troostite borders were wider, until at 1500 degrees Fahr. the quench produced a core of troostite and ferrite, the amount of ferrite being much less than at 1350 degrees Fahr. At 1600 degrees Fahr. the upper limit of the critical range had been reached with elimination of nearly all the ferrite and giving a uniform structure with a troosto-sorbitic appearance. Higher temperatures changed the structure but little, except for increase in grain size and the assuming of a more martensitic appearance. Figs. 5 to 9 show these changes in structure. It will be noticed that the structure consisting of separate grains of martensite and ferrite was harder than the more uniform structure obtained at higher temperatures both below and for some distance above the critical range when in the untempered condition, but the former dropped in hardness rapidly when tempered. The martensite areas in the core appeared quite stable and were attacked less by the etching acid than was the case, although this may have been due to a preferential etching of the surrounding structure. It is suggested that the expansion on the formation of the martensite which would be of practically eutectoid composition at the lower quench, produced strains in the surrounding ferrite which were relieved by tempering and resulted in a decrease in hardness. This point will be further emphasized later in the physical property charts.

The case from the 1350-degree Fahr. quench consisted of martensite and some troostite around the excess carbide in the hypereutectoid zone, (see Fig. 10) indicating that the maximum

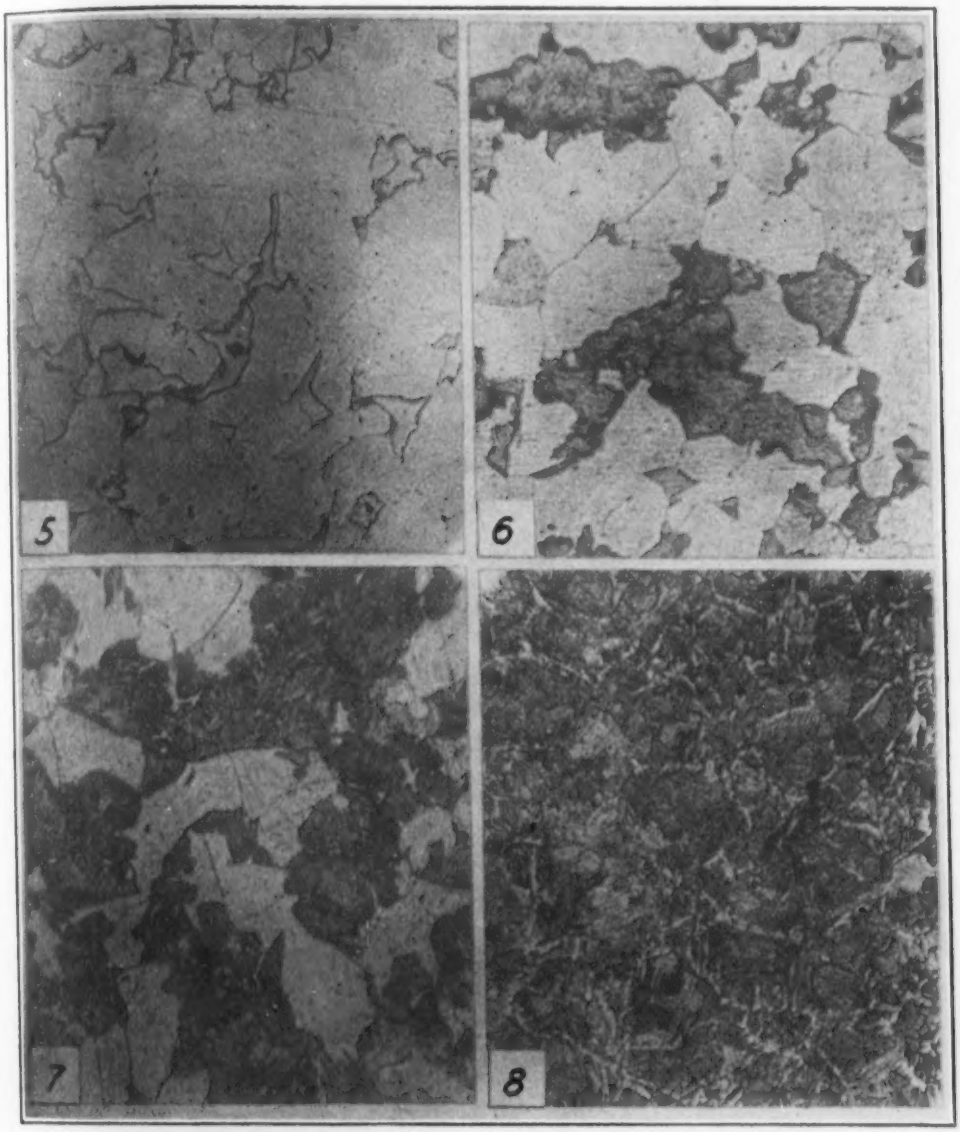

Fig. 5—Core Structure of Steel B, ⅝-Inch Diameter S.A.E. 1020 Steel, Carburized, Cooled in the Box, Reheated to 1350 Degrees Fahr. and Quenched in Water. Structure Consists of Ferrite and Martensite with Narrow Boundaries of Troostite. × 250. Fig. 6—Same Except Quenched from 1450 Degrees Fahr. Ferrite and Martensite with Wider Troostite Boundaries. Fig. 7—Same Except Quenched from 1500 Degrees Fahr. Nearly All Troostite and Ferrite. Fig. 8—Same Except Quenched from 1600 Degrees Fahr. Only a Small Amount of Ferrite Remains in the Boundaries.

hardening temperature for steel of eutectoid composition is lower than for a hypereutectoid steel of otherwise identical composition. From 1400 degrees Fahr. and above, the case was entirely martensitic and at 1550 degrees Fahr. the excess carbide was practically all in solution. The increase in grain size with increase in tempera-

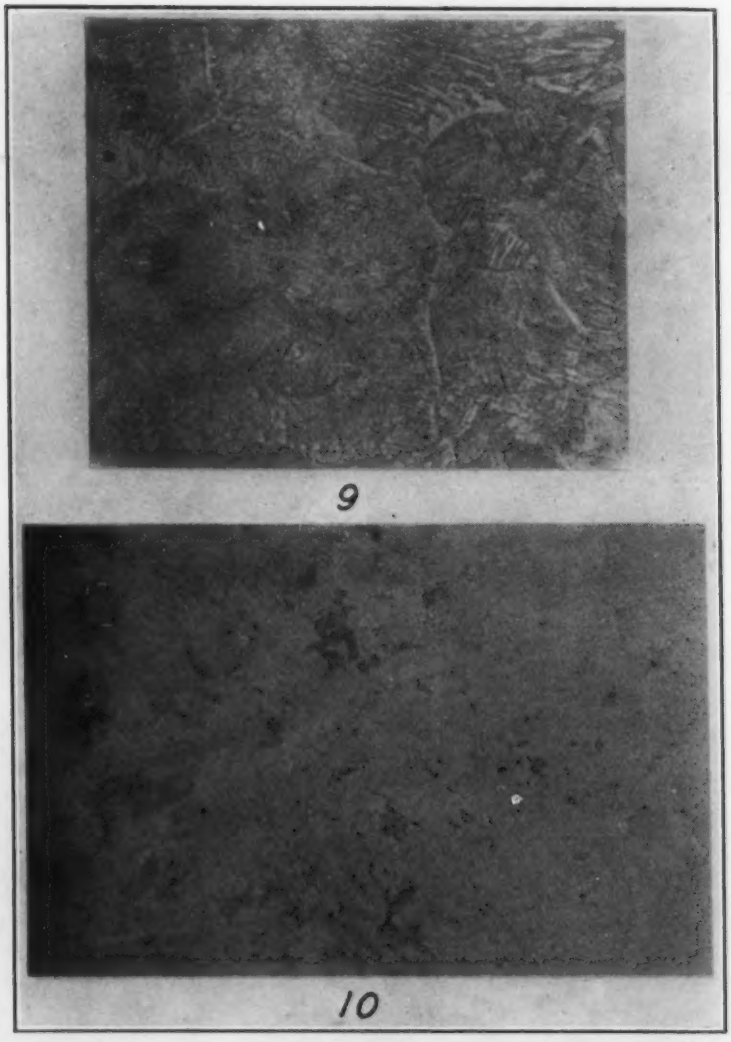

Fig. 9—Same as Fig. 5, Except Quenched from 1850 Degrees Fahr. Coarse-Grained and Very Little Free Ferrite in the Boundaries. Fig. 10—Same as Fig. 5, Except Showing the Case at 100 Diameters Magnification. Note the Troostite Patches in the Hypereuctetoid Zone While the Eutectoid Zone is Almost Entirely Martensitic.

ture was more gradual than in steel A, but the greater part of it occurred between 1700 and 1800 degrees Fahr.

Medium Carbon Steels

Steels C and D (S.A.E. 1035), $\frac{5}{8}$ and $1\frac{3}{4}$-inch diameter respectively, were quenched by violently agitating in water over the temperature range shown in Fig. 11, and Vickers hardness results obtained as shown in the same figure.

The 5/8-inch round samples from 1350 degrees Fahr. consisted of martensite and ferrite on the outside and the same in the center except for narrow boundaries of troostite around the martensite similar to that obtained with S.A.E. 1020. From 1400 degrees

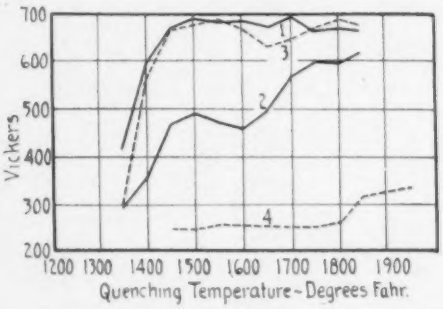

Fig. 11—Curves (1) and (2), Vickers Hardness of Surface and Center Respectively of Bars 5/8-Inch Diameter of Steel C, S.A.E. 1035 Quenched by Agitating in Water. Curves (3) and (4), the Same for Steel D, 1 3/4-Inch Diameter S.A.E. 1035.

Fahr. less ferrite remained and from 1450 degrees Fahr. and above the structure was martensitic on the outside and martensitic and troostitic in the center. The troostite from 1450 to 1700

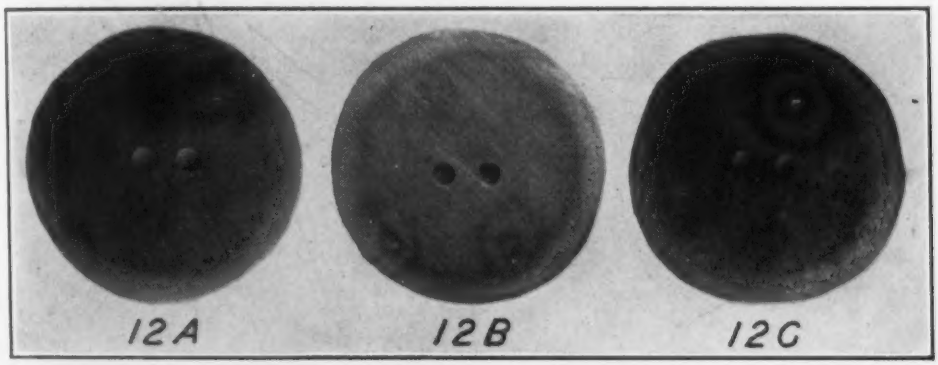

Fig. 12—Photograph of Etched Samples Showing Martensitic Ring Obtained by Quenching Steel D, 1 3/4-Inch Diameter, S.A.E. 1035 Steel, Quenched in Water (Agitated Quench). Quenching Temperature of Sample (A) 1450 Degrees Fahr., (B) 1800 Degrees Fahr., (C) 1850 Degrees Fahr. Samples A and B Appear Quite Similar While the Grain Structure is Much Coarser and the Martensite Deeper in C.

degrees Fahr. was in patches while above this temperature it occurred as narrow boundaries around the martensite. A marked increase in grain size occurred between 1700 and 1750 degrees Fahr., with but slight change above the latter temperature. Very little troostite remained at 1800 degrees Fahr. Fracture tests on these samples showed this same marked difference in grain size.

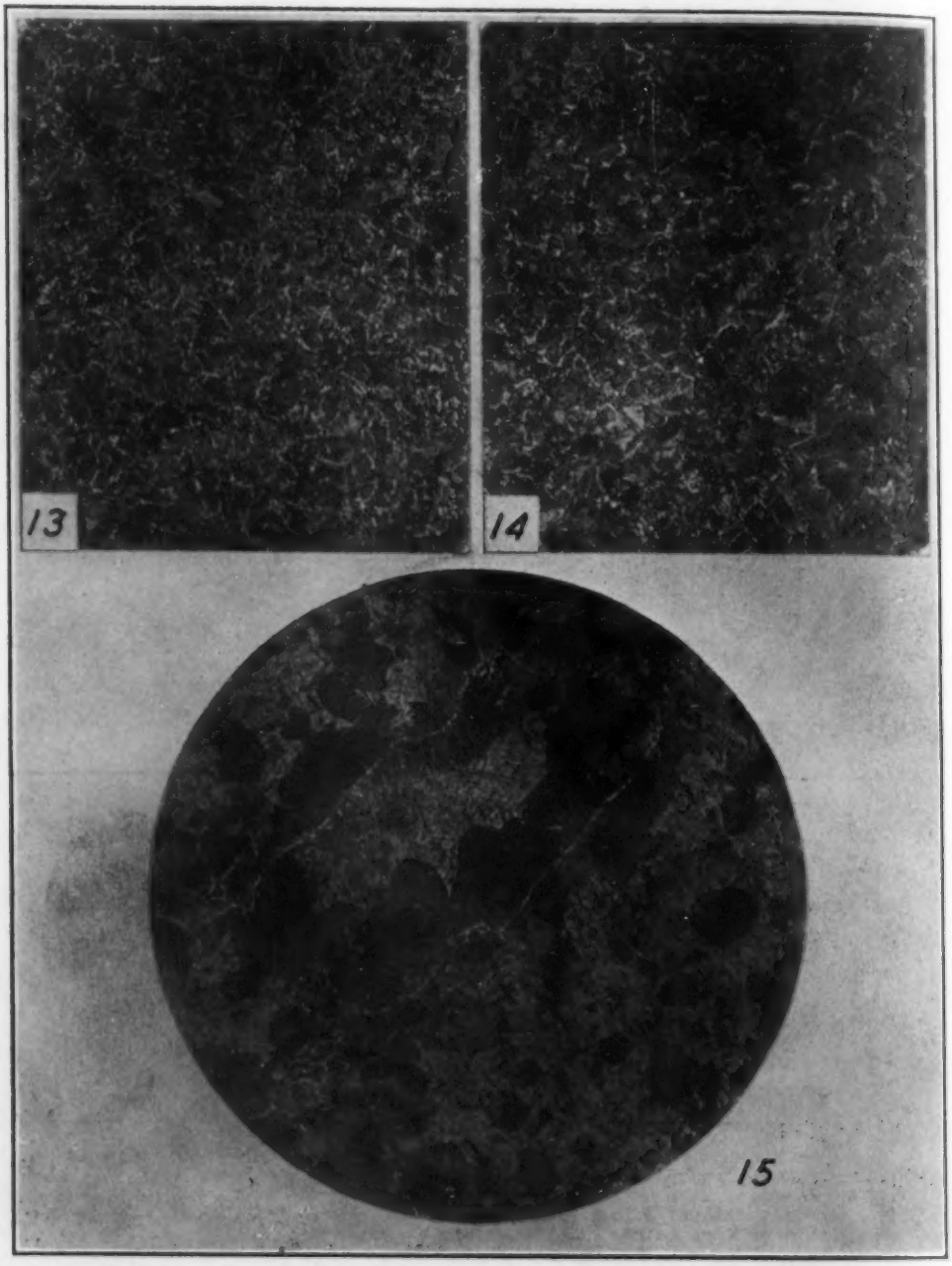

Fig. 13—Photomicrograph of Center of Same Steel and Treatment as in Fig. 12, Except the Quenching Temperature was 1500 Degrees Fahr. × 100. Fig. 14—Same as Fig. 13. Except Quenched from 1800 Degrees Fahr. Fig. 15—Same Except Quenched from 1850 Degrees Fahr.

Cross sections of the bars from steel D, 1¾-inch round S.A.E. 1035, were ground and etched to show the depth of hardness. It was found that the depth of the martensitic ring on all samples

quenched from 1450 to 1800 degrees Fahr. inclusive, was practically the same, being approximately $\frac{5}{32}$-inch deep and uniform around the circumference. The depth at 1850 degrees Fahr. was $\frac{1}{4}$ inch and the grain much coarser. Figs. 12A, B, C are photographs of some of these samples showing the martensitic ring. The fracture tests also showed this marked increase in grain size and the curve shows the large increase in hardness obtained at the center. The

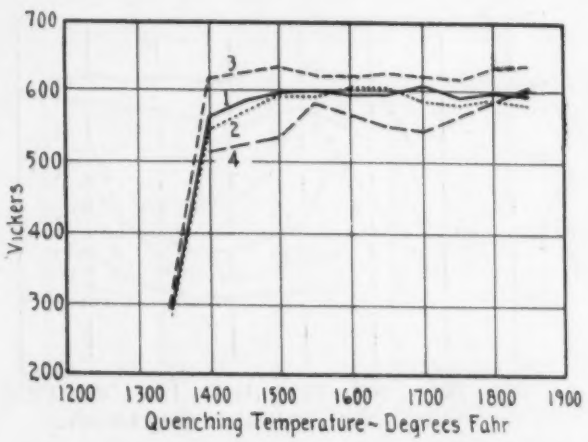

Fig. 16—Curves (1) and (2), Vickers Hardness of Surface and Center Respectively of Bars $\frac{5}{8}$-Inch Diameter, of Steel H, S.A.E. 3240, Given Agitated Oil Quench. Curves (3) and (4), the Same for Steel 1, 2-Inch Diameter, S.A.E. 3240.

microscopic examinations showed martensite on the outside and troosto-sorbite in the center with ferrite boundaries up to 1850 degrees Fahr., and at this temperature the center was martensitic with troostitic boundaries and very little free ferrite. Figs. 13, 14, and 15 show the structures obtained at different temperatures.

A similar procedure was gone through with the $\frac{5}{8}$ and 2-inch round S.A.E. 3240, steels H and I, except that the samples were quenched in oil. The hardness curves for the outside and center are shown in Fig. 16.

With the $\frac{5}{8}$-inch samples a structure consisting of martensite and sorbite with a very little troostite near the outside was obtained from the 1350 degrees Fahr. quench. From 1400 degrees Fahr. the structure was martensitic-troostitic and above this temperature the amount of troostite was small. A marked increase in grain size between 1750 and 1800 degrees Fahr. was noticed in both the microstructure and fracture. The results obtained with the 2-inch round S.A.E. 3240, steel I, were quite similar. The

increase in grain size was a little more gradual, occurring between 1750 to 1850 degrees Fahr. and it will again be noticed that an increase in hardness accompanied it.

The quenches given in the above cases were much more drastic than the ordinary commercial procedure would give. To obtain comparable results, the above experiments were repeated by dropping samples of steels E and F into a basket suspended in a tank

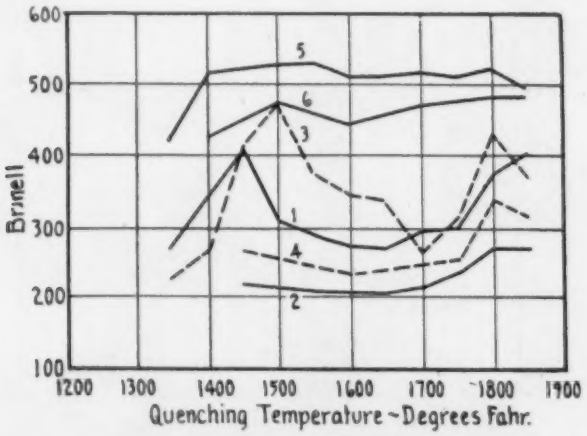

Fig. 17—Curves (1) and (2) Brinell Hardness of Surface and Center of S.A.E. 1035 Steel E, 1¾-Inch Diameter, Quenched by Dropping in a Basket Suspended in Running Water. Curves (3) and (4) the Same for a Front Axle I-Beam Section from Steel F, S.A.E. 1035. Curves (5) and (6), the Same for Steel H, 1⅞-Inch Diameter, S.A.E. 3240, Except Quenched in Still Oil.

through which water was flowing. Steel E was 1¾ inch in diameter, S.A.E. 1035 bar stock, and F, sections cut from the I-beam of a large passenger car front axle. Decided differences in hardness were obtained as shown by the curves in Fig. 17. Note that the hardness values given from here on are Brinell hardness numbers instead of Vickers, unless otherwise stated. The Vickers is more sensitive to small hardness changes and can be used on case hardened parts and is more accurate for very hard pieces. The Brinell operation, however, is quicker and was used where the Vickers was not needed.

Those samples of steel E, quenched at the lower temperature showed rings of martensite around the outside, although irregular and thin in places. Those quenched at the intermediate temperatures were soft, and contained practically no martensite even on the outside, the structure being troosto-sorbite with ferrite grain boundaries throughout. Those quenched at 1800 degrees Fahr.

and above again contained martensite on the outside and a marked increase in grain size and hardness at the center occurred at the same time. The results on the I-beam section were quite similar. The martensite was deeper where hardening occurred because of the thinner section. In the intermediate temperature range, however, practically no martensite was present. The hardness for the center was taken at the center of the largest part of the cross section. The low results obtained on the last two steels certainly

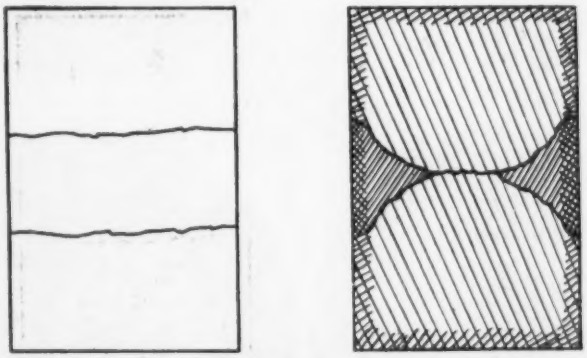

Fig. 18—Diagrammatic Sketch of Carbon Tool Steel G, Quenched in Water from 1700 Degrees Fahr. This Sample Broke in Two Places in Tension, Giving Three Separate Pieces, One Being a V-Shaped Ring in the Center. The Cross-Sectioned Borders Represent Martensite.

have no connection with retained austenite, since in some cases martensite was not even produced. Samples of 1⅝-inch round S.A.E. 3240, steel H, were quenched by dropping into a basket suspended in a tank of still oil. The results were quite similar to those obtained from the agitated oil quench. The Brinell hardness values are also plotted in Fig. 17. The large increase in grain growth occurred between 1750 and 1800 degrees Fahr.

Plain High Carbon Tool Steel

Samples 2 inches in diameter were used, steel G, and quenched by violently agitating in cold water. The samples were allowed to become cold, as hardness values only were to be obtained. The samples quenched from 1700 degrees Fahr. and above were cracked circumferentially with the exception of that from 1750 degrees Fahr., which was not cracked externally. A small transverse load broke this sample, the only part not having failed being a thin ring on the outside, showing that failure in samples so treated

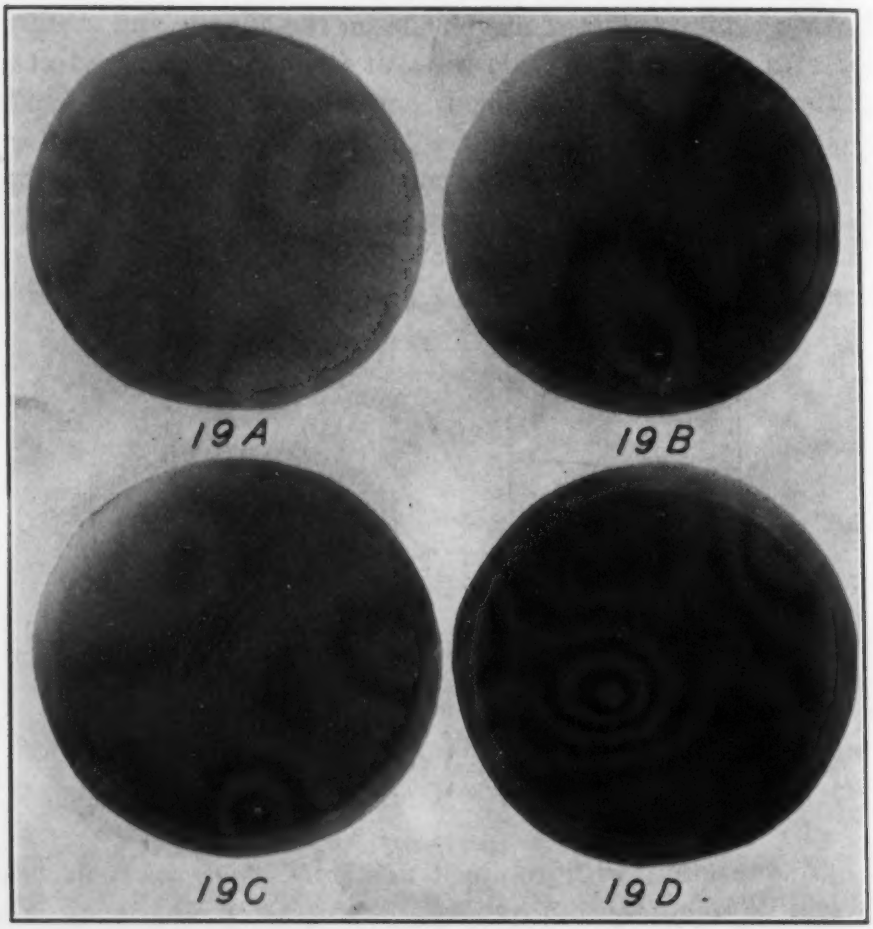

Fig. 19—Photograph of Etched Samples Showing Martensitic Border Obtained on Carbon Tool Steel G, 2 Inches in Diameter, Quenched by Agitating in Water. (A) Quenched from 1400 Degrees Fahr., (B) Quenched from 1500 Degrees Fahr., (C) Quenched from 1600 Degrees Fahr., (D) Quenched from 1650 Degrees Fahr.

starts at the center. The cracked samples, when broken, all showed a cup and cone fracture like that obtained from tensile plugs. The sample quenched from 1700 degrees Fahr. presented an unusual condition in that it failed in tension in two places simultaneously giving three separate pieces, one of which was a V-shaped ring as shown in the sketch in Fig. 18.

The samples were notched, fractures obtained, a cross section ground and etched and some sections obtained for microscopic examinations. The etched cross section from the 1400-degree Fahr. treatment showed a thin but somewhat irregular ring of martensite; on the 1500-degree Fahr. sample, practically no martensite was observable, while at 1600 degrees Fahr. the ring

was about $\frac{3}{32}$-inch deep and fairly uniform; from 1650 degrees Fahr. and higher, the martensitic ring was uniform and about $\frac{5}{32}$-inch deep in all cases. Wright[3] has shown similar results in that no further improvement in die life of plain carbon cold heading dies was obtained when quenching temperatures above 1650 degrees Fahr. were used. Fig. 19 shows the martensitic ring on some of these samples. The microscopic examinations

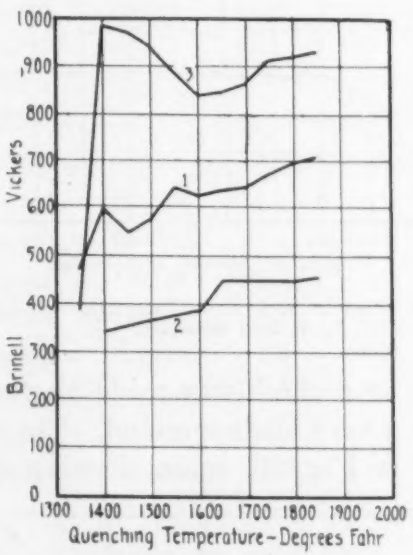

Fig. 20—Curves (1) and (2) Brinell Hardness of Surface and Center of Carbon Tool Steel, G, 2-Inch Diameter, Given an Agitated Quench in Water. Curve (3) Vickers Hardness of Outside Surface.

showed a martensitic outer ring at 1400 degrees Fahr., with a sorbitic center and the excess carbide in the spheroidized condition. At 1600 degrees Fahr. the center consisted of troostite and sorbite and the excess carbide was partly in the boundaries and partly spheroidized. At 1650 degrees Fahr. the center was mostly troostitic and the excess carbide nearly all in solution. The grain size was much coarser than at 1600 degrees Fahr. It will again be noticed that the hardness has also increased at the same time. The change was gradual and not very great above this temperature. The Brinell hardness curves are plotted in Fig. 20.

It will be seen that the Brinell hardness on the surface of

[3] "High Temperature Quenching Treatment Applied to Cold Heading Ball Dies of Plain Carbon Tool Steel." TRANSACTIONS, American Society for Steel Treating, Vol. XIII, No. 2, February 1928, page 282.

the samples quenched from the lower temperature is not as high as that obtained at the higher temperatures which is not in agreement with the smaller samples of carburized S.A.E. 1020 steel. The scleroscope showed the tool steel samples to be harder at the

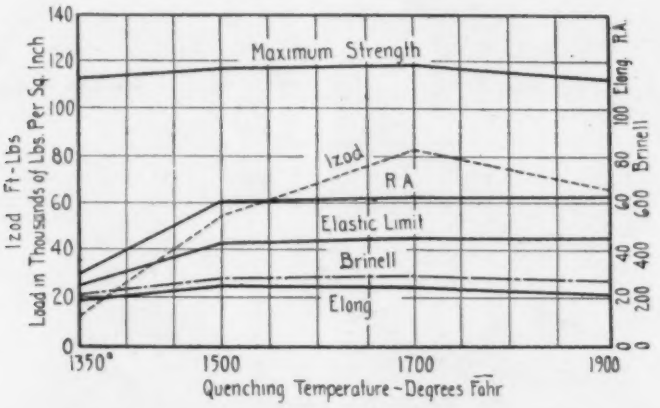

Fig. 21—Tensile and Izod Properties of Oil-Quenched S.A.E. 4615 Steel, J, ¾-Inch Diameter.

lower temperatures, so a check was made on the Vickers machine on the surface after a very shallow grind. The results are plotted in the upper curve in Fig. 20, again showing that the maximum

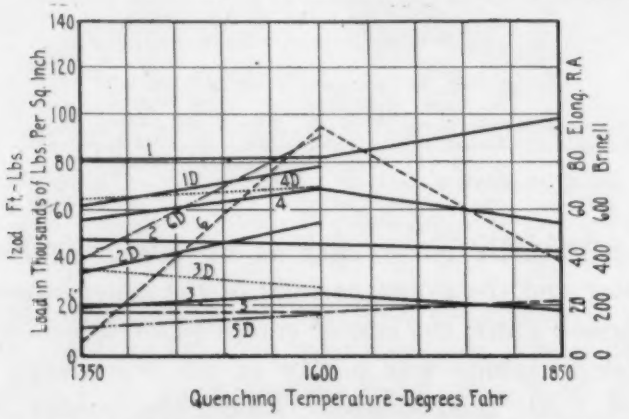

Fig. 22 — Tensile and Izod Properties of Water-Quenched S.A.E. 1020 Steel, B, ⅞-Inch Diameter. Curves (1) and (1D) Maximum Strength as Quenched and After 500-Degree Fahr. Temper, Respectively. Curves (2) and (2D) Elastic Limits for the Same, Curves (3) and (3D) Elongation, Curves (4) and (4D) Reduction of Area, Curves (5) and (5D) Brinell Hardness, and Curves (6) and (6D) Izod Foot Pounds.

surface hardness is obtained by quenching from a temperature slightly above the upper critical range. The softer readings with the Brinell at the low temperatures were probably due to the

Table II
Tensile and Izod Values

No.	Quench	Elastic Limit Lbs. Per Sq. In.	Max. Lbs. Per Sq. In.	% Elong.	% R. A.	Brin.	Izod Notched Bar Ft. Lbs.	Izod Notched Bar Brin.
J1	1350 Oil	25,600	112,900	19.5	32.0	228	13	192
J2	1500 Oil	42,500	117,000	25.4	60.8	248	54	235
J3	1700 Oil	45,000	119,000	25.0	62.6	255	83	235
J4	1900 Oil	45,000	113,150	21.1	63.2	241	66	228
B1	1350 Water	47,500	81,250	19.9	56.1	174	4½	179
B2	1600 Water	45,000	81,900	25.0	68.0	183	96	170
B3	1850 Water	42,500	99,700	18.0	54.9	212	38	223
B4*	1350 Water	35,000	61,550	35.9	64.8	131	39	109
B5*	1600 Water	55,000	78,750	27.0	68.9	166	92	163
K1†	1500 Water	87,500	122,300	23.7	55.6	255	29	255
K2†	1700 Water	82,500	125,300	18.4	49.0	255	41	248
K3†	1850 Water	100,000	157,600	9.8	21.7	311	18	321
L1‡	1500 Oil	115,000	154,000	15.6	48.6	321	44	302
L2‡	1700 Oil	122,500	162,650	14.5	42.9	340	36	321
L3‡	1850 Oil	135,000	169,050	14.1	39.5	351	30	340

*Tempered at 500 Degrees Fahr.
†Tempered at 800 Degrees Fahr.
‡Tempered at 950 Degrees Fahr.

fact that the high hardness on samples of this size did not extend beyond the depth of grinding before making the impression.

Tensile and Izod Notched Bar Values

The test bars from the S.A.E. 4615 and 1020 steels, J and B, were packed in silocel and held at a temperature of 1675 degrees Fahr. for 8 hours and cooled in the pot to give structures comparative to the core of carburized pieces. The bars were then heat treated and test specimens made. Duplicates were made on tensile plugs and 3-notch Izod bars, so that the results given in Table II and shown in Figs. 21 to 24, are averages of 2 tensile and 6 impact results including Brinell readings. The plotted Brinell values are the average of readings on both the tensile and impact bars. Grain size ratings as obtained by the McQuaid-Ehn test are given for these bars, since grain size probably has a considerable effect on Izod values.

Where the properties of the core are important, Fig. 21 shows the need for quenching S.A.E. 4615 steel above the critical range of the core, temperatures below 1500 degrees Fahr. especially should be avoided. The elastic limit, reduction of area, and Izod

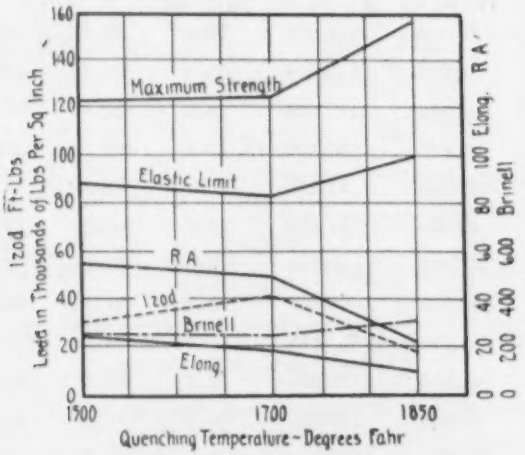

Fig. 23—Tensile and Izod Properties of Steel K, 1⅜-Inch Diameter, S.A.E. 1035, Quenched by Dropping in Flowing Water and Tempered at 800 Degrees Fahr.

values were greatly increased without much increase in Brinell or maximum strength. An Izod value of 83 foot pounds was obtained with a Brinell hardness of 235. The grain size rating was

Table III
Hardness of the Surface of S. A. E. 1035 Bars from which Tensile and Izod Test Bars Were Made

Bar No.	Temperature of Quench Degrees Fahr.	Brinell Before Temper	Brinell After 800 Degrees Fahr.
K1	1500	542	345
K2	1700	375	308
K3	1850	532	345

No. 9. The bars treated were ¾-inch in diameter and quenched by agitating in oil. The elastic limits given in Table II are the true elastic limits obtained with an extensometer.

The S.A.E. 1020 steel, grain size No. 5, and treated as bars ⅞-inch in diameter and given an agitated water quench, presents some very interesting results. The impact value jumped from 4½ to 96 foot pounds by raising the quenching temperature from 1350 to 1600 degrees Fahr., and fell back to 38 when raised to

Table IV

Hardness of the Surface of S. A. E. 3240 Bars from which Tensile and Izod Test Bars Were Made

Bar No.	Temperature of Quench Degrees Fahr.	Brinell Before Temper	Brinell After 950 Degrees Fahr. Temper
L1	1500	486	346
L2	1700	488	347
L3	1850	503	353

1850 degrees Fahr. Those samples quenched at 1350 degrees Fahr., when tempered at 500 degrees Fahr. became much softer and less strong, but greatly increased elongation, reduction of area and impact values were obtained, the latter being increased

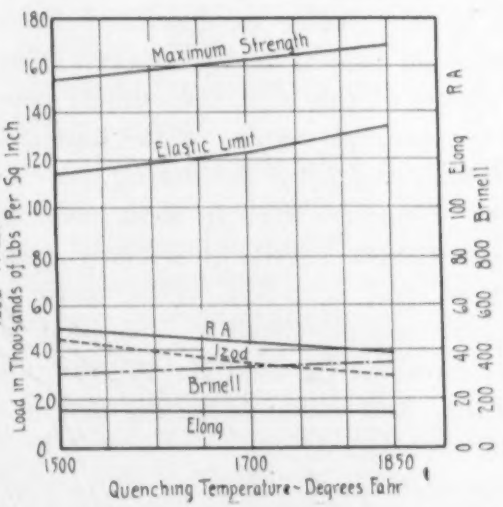

Fig. 24—Tensile and Izod Properties of Steel L, 2 Inches in Diameter, S.A.E. 3240, Quenched by Dropping in Oil and Tempered at 950 Degrees Fahr.

nearly ten-fold by this treatment. This effect on the hardness was previously mentioned and the suggestion made that the relief of the strained condition of the ferrite was responsible, the change being too great to be caused by the small change in microstructure that so low a temper would produce. A similar temper of those samples quenched at 1600 degrees Fahr. had little effect except to raise the elastic limit. This is probably only an apparent raise in the elastic limit due to relief of the strain in the quenched piece as mentioned by Aitchison.[4] It might be noted that as this tem-

[4] "Engineering Steels." By Leslie Aitchison. Chapter IV, page 112.

perature was above the upper critical range little free ferrite remained. Table II and Fig. 22 show the results obtained. Low carbon steel of this composition is frequently heated for bending and other forming operations and quenched in water without subsequent tempering. Where brittleness is to be avoided, the results here obtained show the danger of such a procedure. Care should be taken to quench the steel slightly above the critical range or give it a tempering treatment. The safer procedure would probably be to temper it in either case. The same would hold true for the core of carburized parts.

Fig. 23 shows the results obtained with steel K, S.A.E. 1035, grain size No. 4, but slightly abnormal, showing "clubbing" of cementite. The samples were 1⅜-inch in diameter and quenched by dropping in flowing water as described for steels E and F, and all were tempered at 800 degrees Fahr. The test plugs were made from the center of the bars, the outside being much harder. Table III gives the average results of the hardness of the surface of all the bars before and after tempering.

The physical properties were in most cases such as to be expected from the hardness results previously mentioned.

The bars from steel L, S.A.E. 3240, grain size No. 9, were 2 inches in diameter and quenched by dropping into a basket suspended in oil as mentioned for steel H. All samples were tempered at 950 degrees Fahr., and hardness values on the surface as shown in Table IV were obtained.

The test specimens were cut from the center of the treated bars and the results are shown in Table II and Fig. 24. It will be noticed from the curves that the various physical properties are almost straight line functions of the quenching temperatures.

Summary and Conclusion

In conclusion, the writer realizes that only a limited number of tests have been made and the conclusions arrived at correspondingly in error, but it is believed that the general tendency shown is correct and several of the points have been proved many times in commercial practice. It would require a large number of tensile and Izod tests to accurately establish curves over a range of temperature, and it would also be desired to have results at the same hardness as well as at the same temper. Considerable variation

between different heats of steel, especially in plain carbon types, would be expected. A further point for investigation would be the effect on the physical properties of heating to higher temperatures and allowing to cool to some lower temperature before quenching.

The effects noticed may be summarized as follows:

1. The maximum surface hardness on high carbon steels, either alloy or plain carbon or whether oil or water-hardened, is to be obtained by quenching from a temperature but slightly above the upper critical range. The extreme surface condition of the lower carbon steels was not checked as this is not usually of special commercial importance.

2. Two "peaks" are obtained in the hardness curves, one at temperatures slightly above the critical range, and another at temperatures considerably above those ordinarily used in commercial work. This condition is not so marked in oil hardening steels of medium carbon content.

3. For medium carbon, plain carbon steels in such sizes as automobile axle I-beams, the greatest surface hardness and depth of hardness is obtained by quenching immediately above the upper critical range and the less desirable the quenching conditions, the poorer the results become on raising the quenching temperature unless excessive temperatures of around 1800 degrees Fahr. are used. Temperatures of 1600 to 1700 degrees Fahr. not only cause greater warpage, give more scaling, decrease furnace life and increase fuel costs, but actually give poorer hardening results.

4. Heating a carburized part to a temperature which gave lower hardness and then cooling to a temperature at which maximum hardness was obtained, and then quenching did not give as good results for surface hardness as either a single quench from the low temperature, or a double quench from the higher and low temperature.

5. No matter how drastic the quenching medium may be, a carburized part cannot be tempered so as to produce as high a hardness as when that medium and quenching temperature are used that will give the highest hardness direct from the quench. This would indicate that the decomposition product of austenite is troostite and not martensite, or at least occurs at such a temperature that the martensite is immediately converted into troostite.

6. At a temperature, usually between 1700 and 1800 degrees Fahr., a marked increase in grain size is noticed compared to that occurring either below or above this temperature. The change is more gradual in some samples than others. This temperature would probably be varied somewhat by a change in time at heat. The change is more apparent in fine-grained abnormal steels. Ehn[5] noticed this increase in grain size in his carburizing tests on abnormal steel. No attempt was made to determine the cause of this grain growth. Two theories might be suggested; (1) That there is some kind of a critical range in the iron-carbon system itself at this temperature or what would probably be more reasonable (2) that since the change is greater and more abrupt in abnormal steels which contain a larger amount of impurities, that these impurities enter into a reversible chemical action or go into solution in the austenite and are thus removed as physical barriers to grain growth; or perhaps the effect of the temperature alone overcomes the resistance to grain growth offered by the inclusions.

7. The second "peak" on the hardness curve and a large increase in hardness at the center of larger pieces of steel that are ordinarily not deep hardening occurs at the same temperature as the increase in grain size mentioned in 6 above.

8. Where it is desirable to go to the high quenching temperatures mentioned for such purposes as producing deeply hardened plain carbon tool steel for cold heading die blocks, the proper quenching temperature can be determined with small samples of the same steel by merely noting at what temperature the marked increase in grain size occurs. This temperature had been reached at 1650 degrees Fahr. with the steel used in these experiments. It is desirable to use the lowest temperature possible above that at which the grain growth occurs since higher temperatures give practically no increase in hardness and greatly increase the danger of cracking.

9. Tensile and Izod notched-bar tests on carburizing steels such as S.A.E. 4615 and 1020 show the desirability of quenching slightly above the critical range of the core to obtain greater strength and particularly higher impact values. The effect of a 500-degree Fahr. tempering treatment on low carbon steel

[5] "Influence of Dissolved Oxides on Carburizing and Hardening Qualities of Steel." *Journal*, Iron and Steel Institute. 1922.

quenched within the critical range is very pronounced on the hardness, tensile strength, and notch brittleness.

10. The tensile and notched-bar tests on S.A.E. 1035 and 3240 in general give results that would be expected from the Brinell hardness obtained at different temperatures. After being given the same tempering treatment specimens quenched from the higher temperatures show a decrease in Izod values.

Acknowledgments

The author wishes especially to thank H. W. McQuaid, chief metallurgist of the Timken-Detroit Axle Company, for the interest shown and valuable suggestions given. All materials were furnished by and the work done in the laboratory of the Timken-Detroit Axle Company.

PRINCIPLES OF THE HEAT TREATMENT OF STEEL

An Outline Prepared by the Metallurgical Staff of the Bureau of Standards[1]

Introduction

INFORMATION upon the elementary facts and principles of the heat treatment of steel is sought by several classes of people. Blacksmiths, mechanics, beginners in heat treating shops who heat treat steel according to the foreman's directions and want to understand why the steels they handle behave as they do, salesmen of heat treated steel products and users of such products, all approach the subject with a knowledge of some of the facts, and may well be interested in the principles. A technically trained chemist who may have to assume metallurgical responsibilities may be well prepared to understand the principles of heat treatment as given in metallurgical text books and in current metallurgical literature but may find it desirable to preface the study of such books by reading a more elementary outline.

The large number of requests coming to the Bureau of Standards for concise information on the principles of heat treatment and the suggestion of the Drill Steel Committee of the American Institute of Mining and Metallurgical Engineers[2] that an explanation of those principles be given, have prompted the preparation of this outline. Many inquiries come from persons who do not have access to libraries containing publications on heat treatment and who seek elementary information before purchasing the more complete treatises. This outline is not intended to replace such treatises, nor to contain new information not elsewhere available, but merely to collect and to present elementary principles in as simple terms as the complex nature of the factors involved in heat treatment will permit.

For a good working knowledge it will be necessary for the reader to go much further into the subject than is possible here. Perhaps this outline will encourage the reader to study more complete discussions in books dealing particularly with heat treat-

[1] Published with the approval of the Director of the National Bureau of Standards—not subject to copyright.

[2] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 59, 1923, p. 665.

ment, in periodical literature (such as the TRANSACTIONS of the American Society for Steel Treating and of other metallurgical societies), and the many general text books on metallurgy and metallography, and prepare himself to read such literature with a better understanding.

Publications on heat treatment use many technical terms which need definition before the subject matter can be understood. To facilitate the reading of more detailed and advanced discussions of heat treatment, definitions of the more important technical terms have been included.

While the heat treatment of alloy steel is perhaps of even greater importance than that of carbon steel, a clear understanding of the principles involved in the case of the simple carbon steels is essential to the consideration of the heat treatment of alloy steels. This outline deals in detail only with the carbon steels.

Acknowledgements

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CHAPTER I

FACTORS TO BE CONSIDERED IN HEAT TREATMENT

Object and Operations of Heat Treatment

The object of heat treatment is to make steel better fitted for some specific use. We may change very decidedly the properties of steel by heating and cooling it under certain definite conditions. In order to secure the same results twice in succession, however, the same conditions must be maintained. The proper choice of conditions can only be made with an understanding of the principles involved in heat treatment.

There are steel specimens in the British Museum that were heat treated 3,000 years ago. Yet even a moderately complete understanding of the principles involved dates back hardly 60 years, for the critical point A_1 was discovered by Tschernoff in 1868, while the A_3 point was discussed by Osmond in 1885. These critical points as will be shown later are the cornerstones of the whole structure of the heat treatment of steel.

Effect of Heat on High-Carbon Steel

If we heat a piece of copper (or such a copper alloy, for example, as phosphor-bronze) that has been hardened by cold rolling, cold drawing, or hammering, and allow it to cool slowly, it becomes soft and loses its springiness. If the copper (or phosphor-bronze) is again heated and then quenched in water, it is as soft as it was when it had been cooled slowly. This is the case regardless of whether the metal is heated to a high or low temperature. After the metal has once been softened, neither the temperature nor the rate of cooling affects its properties; we always have soft metal and hardness can only be restored by repeating the cold working operation.

If we heat and then slowly cool a piece of cold drawn steel, such as punches are made from, it too softens *(is annealed)*. Now let us heat it again and plunge it into water. If we have heated it hot enough, when we *quench* it, i.e., plunge it into water, we obtain a material so hard that a punch so hardened can readily be forced through the original rod. A type of hardness quite different from that obtained by cold working has been developed in the quenched steel. Not only is the steel hard, but it is brittle also. If we heat it up a little, it becomes less brittle, i.e., we toughen or *temper* it, as it is termed. If we heat it again and still higher, but not so high as we did before quenching, we continue to soften it or temper it.

We can continue to heat it, hotter each time, quenching it, if we like, as we did after the first heating, and each time it becomes softer until finally we heat it as hot as we did the first time. On quenching it this time, we find it is again hard and brittle. Unlike the hardness imparted by hammering, rolling, or drawing cold metal, the hardness produced in the steel by heating and quenching can be made to appear and disappear at will, according to the

heating and to the treatment we give the steel after heating. That is, by *heat treatment* we control the physical properties of the metal.

Since in order to cause hardening it was necessary to heat to a definite temperature before quenching it is clear that we have to control the temperature to obtain results. The ancient armorer who made, quenched, and tempered forty-nine swords, none of which were good enough, only succeeding on the fiftieth attempt in making one to meet the king's specifications, would not get on very well if he tried to make heat treated parts for a modern automobile. One of the most important differences in his equipment and that of a modern heat treating shop is that the modern shop has pyrometers,—instruments for measuring high temperatures much as a thermometer measures atmospheric temperatures.

Let us put the end of a sufficiently sensitive pyrometer (the hot junction) in the middle of a pile of pieces of the punch steel so that the instrument will show the temperature of the steel itself. We heat the steel, meanwhile watching the pyrometer needle which swings up slowly, never halting. When the needle reaches 1325 degrees Fahr. on the pyrometer scale we take out a piece and throw it into water, to be examined later. The needle crawls on to 1350 degrees Fahr. where it halts a trifle, before it continues to advance, as if something were happening in the steel that absorbed heat and stopped the rise of temperature while it lasted. Now the temperature rises again and at 1375 degrees Fahr. we take out another piece and quench it; at 1425, 1475 and 1525 degrees Fahr. we take out others, marking each one so we can tell it from the others. We examine the pieces by breaking them in a vise, with the following results:

1325 degrees Fahr.—soft and tough, bends before breaking.
1375 degrees Fahr.—hard, very fine grained broken surface.
1425 degrees Fahr.—hard, somewhat coarser broken surface.
1475 degrees Fahr.—hard, still coarser broken surface.
1525 degrees Fahr.—hard, very coarse broken surface.

The 1375-degree Fahr. temperature is the lowest one we have tried that gives us hardening on quenching, and takes the least fuel for heating, so we adopt that, for the present at least, for this particular steel.

Suppose now we machine a gear from a large piece of this

steel we have been using and heat and quench it in water as before. It will be liable to crack on quenching, or soon after. If we measure the gear, we find it is larger after quenching than it was before. It appears that the steel has expanded. We wonder if we have to quench the steel or whether it is only necessary to heat it hot enough and let it cool, so we try cooling another gear in the air. This time the gear does not crack, and it does not show any expansion when we measure it. We test its hardness and find it is somewhat harder than when we slowly cooled (annealed) it, but nowhere near as hard as when we quenched it in water. So we try cooling it in another liquid, say oil. This time the gear does not crack and it is hard, perhaps not quite as hard as when we quenched it in water, but still hard enough to serve as a gear. We find on measurement, that it has expanded. The expansion must have something to do with producing the hardness we require. Some changes have gone on in the steel that give us both hardness and expansion, and the control of these changes depends not only on the temperature but also on whether we cool it rapidly as in water, slightly less rapidly as in oil, still less rapidly as in air, or very slowly as by allowing it to cool down with the furnace. Temperature and rate of cooling both play a part.

Effect of Heat on Steel of Low and Medium Carbon Content

Let us take another kind of steel, such as is used for many forged automobile parts and often called forging steel, and heat it to 1375 degrees Fahr. and quench it. We find that it hardens, though it does not become quite so hard as the punch steel did. On heating pieces of this steel and watching the pyrometer as we did before, we find *two* temperatures at which the pyrometer needle halts, one at 1350 degrees Fahr. as before and another at 1450 degrees Fahr. (The second halt is only a slight one, and a more sensitive apparatus than the usual pyrometer would show it more clearly). On examining a number of pieces quenched from successively higher temperatures we find that the best temperature for full hardening without too coarse a grain is 1475 degrees Fahr. or 100 degrees hotter than was best for the punch steel. The quenched forging steel is not quite so hard and somewhat less brittle than the quenched punch steel. Then we try a softer steel such as an automobile frame might be made from. We find a halt

at 1350 degrees Fahr., as before and a second one at 1550 degrees Fahr. So we try quenching from 1575 degrees Fahr. The steel hardens somewhat but is not so hard as our quenched forging steel, and is quite tough. Perhaps the pyrometer has not guided us correctly, so we try again, this time quenching several pieces at different temperatures. We find that the 1575-degree Fahr. quench really was the best, and that the highest hardness we can get from this steel by quenching in water is not so great as in the other steels.

Effect of Heat on Iron

Next, we try a piece of open-hearth ingot iron, i.e., nearly pure iron. This time the laboratory pyrometer outfit does not show a halt at about 1350 degrees Fahr. as it did in all the other steels, but goes up to 1650 degrees Fahr. before it halts. We try quenching from 1675 degrees Fahr., but the iron does not harden materially. Likewise, quenching from higher temperatures produces no material hardening of the iron. Evidently ingot iron is different from steel, even though it has something happening inside on heating, which affects the pyrometer. In fact, each steel acted differently from the others.

Effect of Composition

Suppose we get a chemist to analyze these four lots and find out what they contain besides iron, which we know is present. He reports as follows:

Elements	Ingot Iron Per Cent	Auto Frame Steel Per Cent	Forging Steel Per Cent	Punch Steel Per Cent
Carbon	0.01	0.20	0.40	0.90
Manganese	0.02	0.40	0.55	0.35
Silicon	trace	0.05	0.05	0.10
Sulphur	0.025	0.04	0.03	0.02
Phosphorus	0.005	0.03	0.03	0.02
Iron by difference	99.94	99.29	99.04	98.61

The only element that increases steadily as the ability to harden on quenching increases is carbon, so it is plain that the chief difference between ingot iron and steel lies in the carbon, and that steel is a combination or alloy of iron and carbon with an appreciable quantity of manganese.

Chart of Composition and Temperature

In order to predict what will happen in steels of other carbon contents, the percentages of the other elements, excepting iron, remaining about the same, let us draw a chart such as Fig. 1, in which we show both the percentage of carbon and the temperature of the pyrometer halts.

We know that the halt at 1350 degrees Fahr. does not occur at zero carbon so we will draw the lines around the point P dotted.

Names and Structure of Constituents of Steel

It would be a good plan to have shorter names for steel in these different fields than to refer, for example, to steel above the line GOS as "steel at such a temperature and of such a carbon content that when quenched it will harden fully." The names in use are those that not only represent these fields but also represent the structure of the steel as seen through the microscope.

If a piece of annealed steel is smoothly ground, polished to a mirror-like surface and then slightly attacked or "etched" in a dilute acid such as nitric acid or picric acid and examined under the microscope, magnifying it to say 100 or 500 times its original diameter (10,000 or 250,000 times its original area and usually denoted by "$\times$ 100" and "$\times$ 500"), we can see much more of the details of its structure than we can with the naked eye, although the elements or atoms that are the building blocks from which the steel is really made up are still millions of times too small to be seen through the microscope. The magnified steel is seen to be made up of crystalline grains which are not all alike; some are light and some are dark.

Let us examine our four specimens under the microscope, magnifying them to 100 diameters after they have been heated above the temperature indicated by the line GOS in the chart, Fig. 1, and allowed to cool in the furnace so as to have time to take up the condition in which they are most stable, i.e., to come to equilibrium. A somewhat more complete chart than the one in Fig. 1, drawn to show the equilibrium conditions, is called the "iron-carbon equilibrium diagram." Such a diagram for conditions obtained on heating appears in Fig. 3.

We find that the annealed ingot iron, containing practically

no carbon, is made up of irregular grains that are all practically alike, Fig. 2A. Since we need a name to represent these grains as seen under the microscope, one that will not be confused with the terms, wrought iron or cast iron, but will represent pure iron after annealing and cooling, we make one from the Latin word from iron (ferrum) and call the practically pure iron, *ferrite*. The ingot iron sample contains only ferrite, except for a few "inclusions" of sulphide of manganese, oxide of iron, slag, etc., which

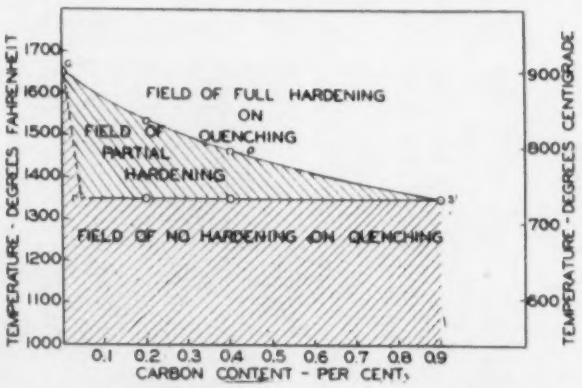

Fig. 1—Chart Showing Temperature Required to Produce Hardening, on Quenching, of Steels of Different Carbon Contents.

are not metals, but chemical compounds of metals with non-metallic elements like sulphur and oxygen. The metallic manganese, silicon and phosphorus cannot be seen. They are uniformly distributed through the iron as atoms which we cannot see. That is, these elements are dissolved in the solid iron much as sugar is dissolved in water. The 0.01 per cent carbon is not visible either, that is, ferrite can dissolve some metals and a very little carbon without being distinguishable from pure iron under the microscope. This idea of a *solid* solution is going to be of service to us hereafter. If one puts a bit of solid brownish-purple iodine against a crystal of solid white potassium iodide he can see the iodine diffuse through the potassium iodide and stain it brown, so the fact that a material does not have to be liquid to dissolve another is clear. Our ingot iron then is a single solid solution called ferrite. We could put in several per cent of nickel and the crystals would still look the same and would still be called ferrite, or if we want to distinguish it from pure iron, nickel-bearing ferrite.

But when we look at the annealed auto frame steel under the

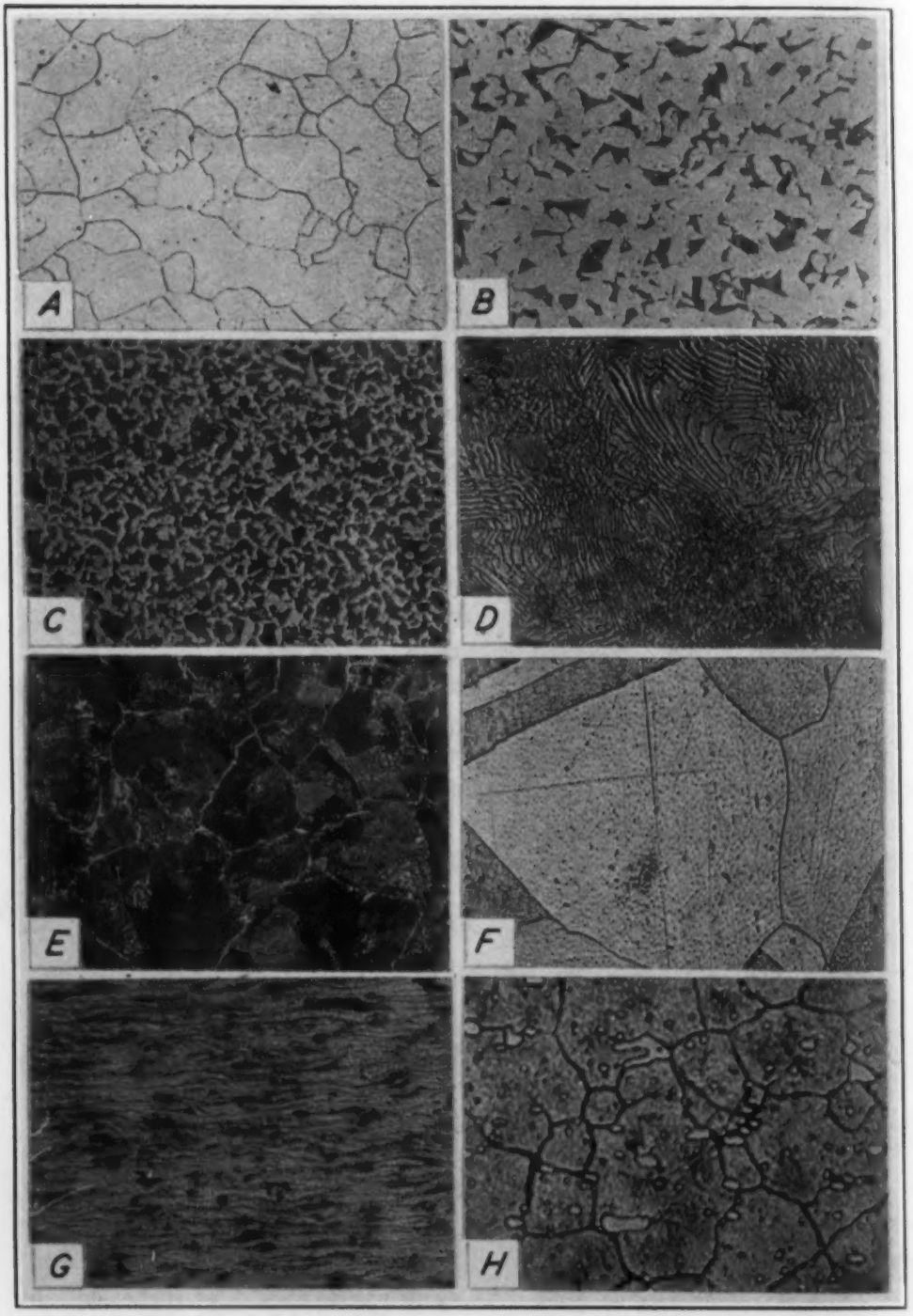

Fig. 2—Typical Microstructure of Various Steels. a. Pure Iron, Ferrite. × 100. b. Auto Frame Steel, 0.20 Per Cent Carbon, Ferrite and Pearlite. × 100. c. Forging Steel, 0.40 Per Cent Carbon, Ferrite and Pearlite. × 100. d. Punch Steel, 0.90 Per Cent Carbon, Pearlite. × 500. e. Tool Steel, 1.20 Per Cent Carbon, Pearlite with Cementite Network. × 100. f. High Nickel Steel (28 Per Cent Nickel), Austenite. × 500. Etchant 1 Part Nitric Acid, 1 Part Acetic Acid, 2 Parts Water. g. Cold-Worked Low Carbon Steel, 0.15 Per Cent Carbon, Work Lines in the Ferrite. × 100. h. High Speed Steel (Carbon 0.71 per Cent; Manganese 0.31 Per Cent; Chromium 3.60 Per Cent; Tungsten 12.75 Per Cent; Vanadium 1.99 Per Cent; Quenched from 1290 Degrees Cent. (2354 Degrees Fahr.) in Oil, Austenite and Carbides. × 750. Etchant 5 Per Cent Picric Acid, Except f.

microscope, Fig. 2B, we see two sorts of crystal grains instead of one. One sort is light and looks like the ferrite of the ingot iron sample. It is the same and it makes up about three-quarters of the mass. The other one-quarter is dark, and is plainly something else. Since it is the carbon that makes the difference between iron and steel, we suspect that the carbon is in the dark grains. But since the carbon amounts to only 0.20 per cent and we have 25 per cent of the mass that is dark, the dark constituent must contain both carbon and iron. If we examine the forging steel, Fig. 2C, with 0.40 per cent carbon, we find the same two constituents, the one light, which is ferrite and in this case makes up only about half the mass, the other dark making up the other half.

If we then examine the punch steel with 0.90 per cent carbon, at 100 diameters we find only a dark confused structure with none of the light ferrite. See Fig. 12—(3). It looks like the areas within the network of Fig. 2E. We have 100 per cent of the dark constituent. If we magnify the dark structure still further, say to 500 diameters, we find that instead of the dark mass being uniform, it is really made up of thin alternate layers of a light and dark substance, Fig. 2D. The layer formation makes it appear shiny like mother-of-pearl and hence this formation has been given the name, *pearlite*. Since the Latin word for layers is "lamellae," the pearlite is still further described as "lamellar pearlite." Now we have to find out what the two layers are.

Going back to the 0.20 per cent and 0.40 per cent carbon steel samples and examining them at 500 diameters, we find that the parts that looked dark at 100 diameters have the same layer structure as we found in the 0.90 per cent carbon steel. All the dark patches are pearlite. We note, too, at 500 diameters that the thicker layers of the layer structure look like the ferrite. As a matter of fact, they are ferrite.

This leaves only the thinner layers of the pearlite still undetermined. Obviously, they must contain carbon, but since carbon could not make up so large a part of the mass, they must contain iron too, and a good deal of it. It has been shown by dissolving out the ferrite and analyzing the residue of the thinner layers, that these layers contain 6.7 per cent carbon and 93.3 per cent iron. Since the atom of iron is heavier than that of carbon,

(having an atomic weight of 56 against only 12 for carbon), it figures out that these layers have just three times as many atoms of iron in them as they have carbon atoms. That is, we have a definite chemical compound of three atoms of iron and one atom of carbon, or using the chemical symbols for iron and carbon (Fe for iron, from "Ferrum," and C for carbon), it is Fe_3C.

This definite iron-carbon compound, Fe_3C, iron carbide, is called *cementite,* because we can readily form it in the cementation or case hardening process in which iron is heated in contact with carbon and takes up carbon.

Hence, we find that *pearlite* is really made up of *ferrite* and *cementite,* about 85 per cent ferrite to 15 per cent cementite by volume, i.e., the ferrite layers are the thicker ones.[3] So we have in all the four annealed samples (aside from non-metallic inclusions) only the two constituents, ferrite and cementite.

If we were correct in thinking that at 0.9 per cent carbon, we had 100 per cent of pearlite which consists of a mixture of ferrite and cementite in a definite ratio, then 0.9 per cent carbon will be a turning point. If we add more carbon, we should get more cementite in addition to that in the pearlite. This would be "free" cementite.

If we examine a 1.2 per cent carbon tool steel, we find that it does contain a network of free cementite, Fig. 2E. This network is so hard that it resists abrasion on polishing and hence stands in relief. It is brilliant white after etching while the pearlite is dark.

Furthermore if we watch the pyrometer on heating up the tool steel we find that the halt takes place at the same temperature as it did in the 0.9 per cent carbon steel, but we do not find another above that temperature as we did when we had free ferrite. Free cementite and free ferrite therefore act differently.

Let us imagine a microscope so arranged that we could watch a steel specimen during heating[4]. Take the annealed 0.90 per cent carbon pearlitic steel. If we heat it there is no change in the pearlite till we reach 1350 degrees Fahr. At this temperature a re-

[3]One "point" of carbon, 0.01 per cent, gives 0.15 per cent cementite or 1.10 per cent pearlite. A change of 5 points in carbon means a change of 5½ per cent in the amount of pearlite.

[4]Such an arrangement would be very difficult to rig up, since the microscope lens would get too hot, and it would be necessary to use some corrosive gas for etching. Were it practicable to set up such an apparatus the changes of the kind mentioned would be looked for.

markable change takes place, the structure loses its dark confused appearance and appears light and uniform, the "dark" masses disappear and go into solid solution. We have only one kind of crystals (just as is the case in the annealed ingot iron which is all ferrite), but since we have seen that ferrite can dissolve only a few hundredths of a per cent of carbon, this cannot be ferrite, it must be a *different kind of iron* which is capable of taking quite large amounts of carbon into solution. (Fig. 2F shows the high temperature variety of iron, the photomicrograph being taken at room temperature. This material is not that of a plain carbon steel, but looks the same as the carbon steel of 0.90 per cent carbon would above 1350 degrees Fahr.) If we should watch the sample of ingot iron as it was heated up, we would see that at 1650 degrees Fahr. the small ferrite crystals change over into larger crystals. These crystals above 1650 degrees Fahr. would look like those of 0.90 per cent carbon steel above 1350 degrees Fahr.

If we heated the 0.20 or 0.40 per cent carbon steels, we would find that each, as we go above 1350 degrees Fahr., loses its dark (pearlitic) areas and forms larger, light crystals, just like those that we got suddenly on heating the pure pearlite or the pure ferrite, and these slowly absorb or eat up the free ferrite till at 1550 degrees Fahr. for the 0.20 per cent carbon and 1450 degrees Fahr. for the 0.40 per cent carbon steel, only one sort of crystal, the sort that dissolves carbon, would remain.

If we take the 1.2 per cent carbon steel, we find that at 1350 degrees Fahr. all the pearlite changes to these carbon-dissolving iron crystals, and they slowly eat up the free cementite till at 1600 degrees Fahr. the last of the cementite is gone. (The change at 1600 degrees Fahr. is not readily shown by a pyrometer, its existence is best shown by the examination of the microstructure of heat treated specimens).

Iron-Carbon Diagram

We can now add to Fig. 1 and draw Fig. 3. We have names for all the micro-constituents save for the kind of iron that dissolves carbon. In honor of an Englishman who cleared up many points about the iron-carbon chart or diagram, Roberts-Austen, this is called *austenite*. Another name or symbol for this is the third letter of the Greek alphabet, gamma (γ). If we use a sufficiently

sensitive pyrometer and method, we can find another halt in the heating curve at 1420 degrees Fahr. so that strictly there is a slightly different kind of iron above that temperature which has been given the second letter of the Greek alphabet, beta (β) as its symbol. (We do not know just what causes the 1420-degree Fahr. halt nor exactly what the difference is between alpha and beta iron, but we need not consider beta iron since it appears to play

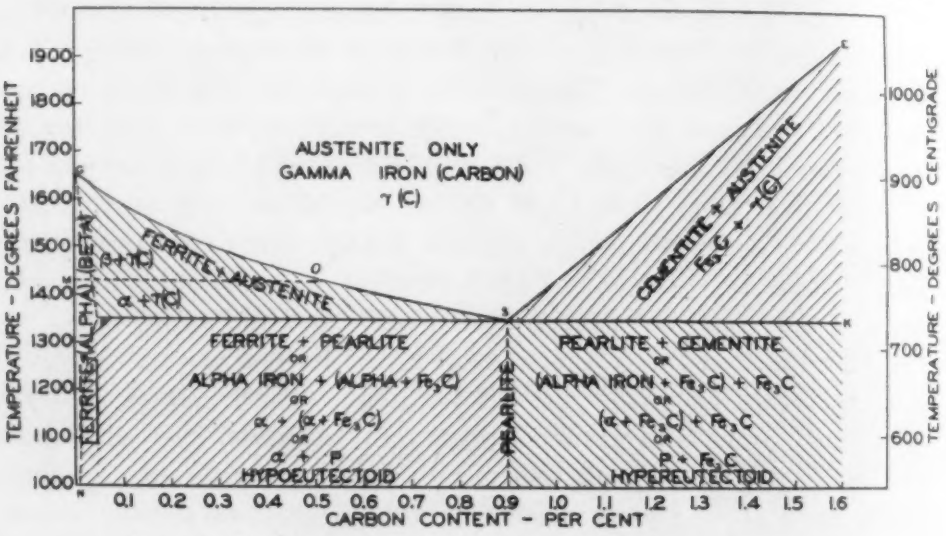

Fig. 3—The Iron-Carbon Diagram, Showing Changes on Heating.

no part in practical heat treatment). Finally, ferrite is given as its symbol the first Greek letter, alpha (α). Now we can name or symbolize all the fields of Fig. 3. When we use such a symbol as γ (C) it means that carbon is in solution in gamma iron, while one like α + P means that we have two constituents together, alpha iron and pearlite. We let P stand for pearlite as it is not a chemical compound, merely a mixture, while for cementite we will use the regular chemical symbol, Fe_3C. These names ought to be learned, as they form a shorthand much used in metallurgical literature, and unless they are understood, the advanced books on heat treatment will not be intelligible.

Other terms that are used are *eutectoid, hypo*eutectoid and *hyper*eutectoid. A eutectoid carbon steel is one of 0.90 per cent carbon, i.e., one that is all pearlite, because this composition, as shown in Fig. 3, has the $\gamma \rightarrow \alpha$ (gamma to alpha) change occurring at only one temperature, and that temperature the lowest one at which that change does occur. The term is similar to eutectic,

which refers to the lowest melting alloy between two metals, the ending *oid* being used instead of *ic* to differentiate between changes that occur in solids, like austenite, from those that occur in a liquid melt. *Hypo*eutectoid means "of less than eutectoid composition," i.e., less than 0.9 per cent carbon, while *hyper*eutectoid means "of more than eutectoid composition," i.e., more than 0.9 per cent carbon, terms "hypo" and "hyper" being taken from the Greek and meaning under and over respectively. It should be easy to remember that a eutectoid steel contains 100 per cent pearlite, a hypoeutectoid steel contains free ferrite and less than 100 per cent pearlite, while a hypereutectoid steel contains free cementite and less than 100 per cent pearlite. Most tool steels contain free cementite and are hypereutectoid; softer steels contain free ferrite and are hypoeutectoid.

The kind of iron that dissolves carbon, i.e., austenite, (gamma iron) has been shown, by reflecting a beam of X-rays from the iron at different temperatures, to crystallize differently from ferrite, (alpha iron), while beta iron crystallizes just as alpha iron does. Another difference between alpha iron and the other forms is that alpha is magnetic, while beta and gamma are nonmagnetic. As we have said, beta iron plays no part in heat treatment, but it is evident that the change from gamma to alpha iron does. This $\gamma \rightarrow \alpha$ change and the formation of cementite, Fe_3C, are the two chief factors to which we must look for the explanation of the principles of heat treatment.

In Fig. 3 the dotted lines GPN are drawn as shown by Hanson[5], in order to indicate roughly the probable facts as to the solubility of carbon (or of cementite) in alpha iron. Just what this solubility has to do with ordinary heat treatment is not yet very clear and need not be considered for the purposes of this outline.

CHAPTER II

Effect and Purposes of Heating

Formation of Austenite

For a steel to harden on quenching, its ferrite must be first changed into austenite, so it can hold carbon in solution. There

[5]Hanson, D.—Discussion of Whiteley, J.—"The Solution of Cementite in Alpha Iron and its Precipitation." *Journal*, (British) Iron and Steel Institute, Vol. 116, 1927, p. 306.

is some question whether the carbon dissolved in austenite is there as cementite, which has each carbon atom chemically joined onto three iron atoms (Fe_3C), or whether the cementite breaks up, at 1350 degrees Fahr., to iron and free carbon. It probably does break up. If so, the iron thus freed changes to gamma iron just as ferrite does. The carbon, whether free or combined, goes into solution in austenite. It is rather more likely that it is there in the form of free carbon. The steel must be heated above the line PSK, Fig. 3, before we have any gamma iron so that no hardening will take place in any carbon steel on quenching unless we heat it above 1350 degrees Fahr. Since we cannot harden ferrite by ordinary quenching, *all* the alpha iron ought to be changed to gamma, so that all heat treating by quenching, all true annealing and all normalizing (a term that will be defined later) as well, is done by heating, *not only* above PS but also above GOS. In high carbon tool steels (hypereutectoid) it is not always necessary to go above the line SE.

Heating of Steel

As a general rule the thing to do before quenching is to get *all* the ferrite and pearlite and often all the cementite into solution in austenite. Now while we are changing alpha iron into gamma iron and taking some cementite (that of the pearlite, or free cementite itself) into solution in gamma iron by heating above PSK, whatever the carbon content of the steel, we must remember that in the cases of hypoeutectoid or hypereutectoid steels we have patches of ferrite or a network of cementite, respectively (Figs. 2B, 2C and 2E), that differ greatly in composition from pearlite.

Homogeneity and Grain Size

In pearlite as in eutectoid steel, the layers of ferrite and cementite are so sandwiched together that the carbon of the cementite does not have to travel far when it dissolves in the gamma iron that forms from the ferrite, so the solid solution of carbon in austenite formed from pearlite very quickly becomes homogeneous. It is different in any steel but one of eutectoid composition, particularly in those with low carbon contents. The pearlite areas of Figs. 2C, 2B, for instance, will readily become homogeneous austenite, but it takes time for the carbon to diffuse from those 0.9 per

cent carbon austenite areas through the carbon-free gamma iron formed from the free ferrite, and bring the composition at *every* point back to the 0.2 per cent carbon, the average composition of the steel, and make the steel all austenite of uniform carbon content rather than a patch-work of spots of different carbon content.

Naturally, this diffusion would take place more rapidly at higher temperatures than the line GOSE. It happens that as long as austenite is busy attending to the diffusion of carbon, it does not have much chance to look after grain growth. But as soon as it is fairly contented with the uniformity of carbon within it, it starts to grow big grains, and this too, goes on much faster at high temperatures. Fig. 4A shows the size to which the grains may grow on improper heating. If we allow the grains of austenite to grow too large, the steel after quenching will be more brittle. Hence, it is very important in heat treating a forged or worked carbon steel not to heat the austenite to too high a temperature. We might better hold the temperature as little above GOSE as possible and give the austenite plenty of time for diffusion of carbon so that the action will be going on slowly enough so we can stop it before we have gotten what we do not want, growth of large grains.

There are some exceptions to this. Steel castings have rather large crystals anyway, and tend to have *dendritic* or pine-tree structure, Fig. 5. To destroy this structure and get uniform austenite we may have to heat the steel much hotter than we would one with a fine initial structure, like that of a carefully finished forging. (The forging process mashes the original crystals up so that diffusion is much easier than in castings). But, with a plain carbon steel, it is a good rule not to heat any hotter before quenching than one has to. Some alloy steels will stand higher temperatures than carbon steels, and some do not stand so high a temperature. There are some cases even in carbon steels where one gets better hardening on quenching from a slightly higher temperature than would be expected from this rule, but the reason probably lies in the effect on the rate of cooling rather than in the factors here considered.

Quenching from high temperatures is also objectionable since it increases the tendency toward cracking and warping. If steel intended for quenching is accidentally somewhat overheated, it should not be quenched, but be allowed to cool in the air, then be

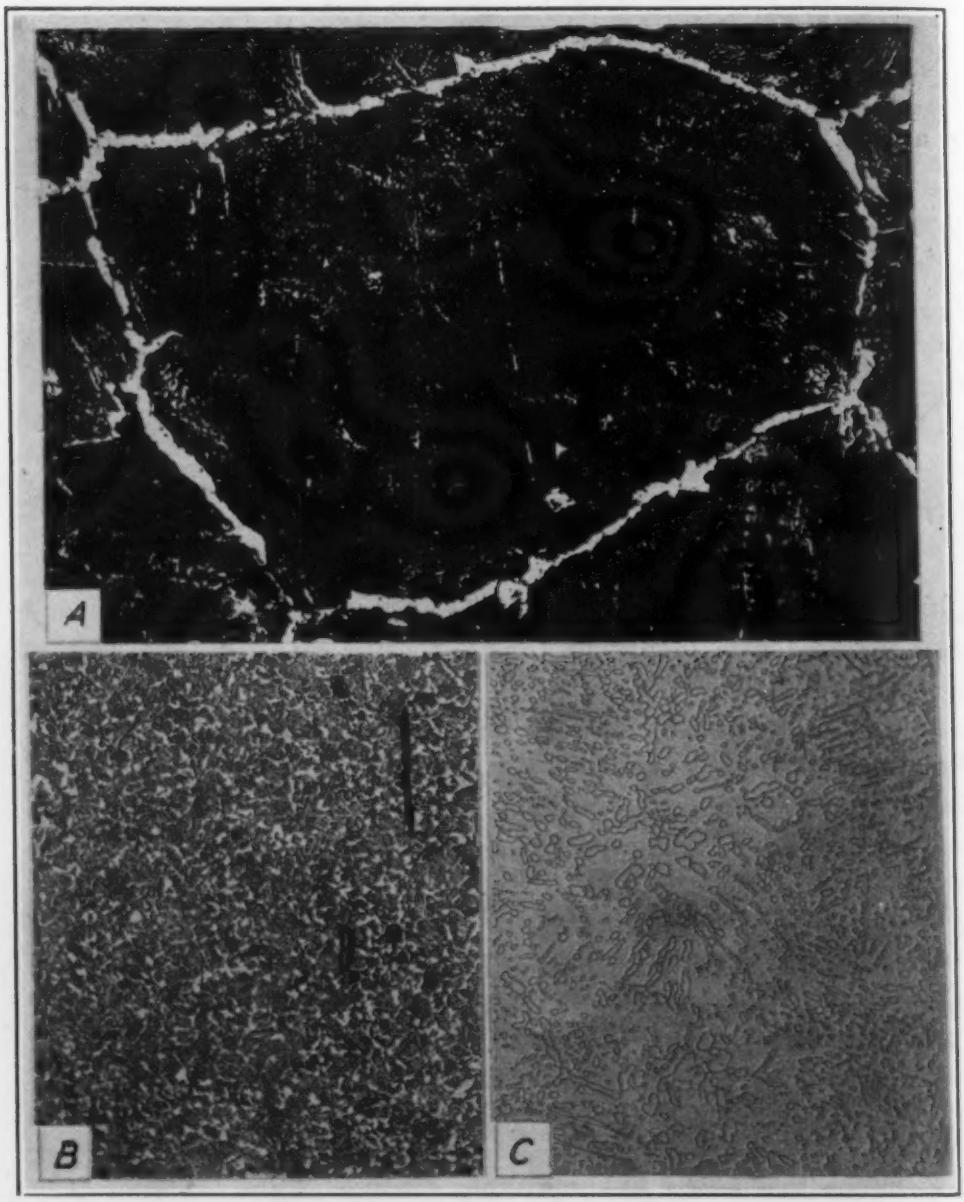

Fig. 4—Decided Variations in Grain Size Produced by Heat Treatment. × 100. a. Very Coarse Grain Produced by Improper Annealing at too High a Temperature (Heated 6 Hours at 2030 Degrees Fahr. (1110 Degrees Cent.) b. Fine Grain in Normalized Steel. The Two Long Particles are Non-Metallic Inclusions. Etchant 5 Per Cent Picric Acid in Alcohol. c. Spheroidized Structure in Tool Steel. × 500. The Background is Ferrite; the Sharply Outlined Particles are Cementite. This Steel Contains 1.1 Per Cent Carbon. Etchant 5 Per Cent Picric Acid in Alcohol.

annealed at a temperature just above the critical range, slowly cooled, and finally then again heated to a proper temperature for quenching. At extremely high temperatures the steel becomes

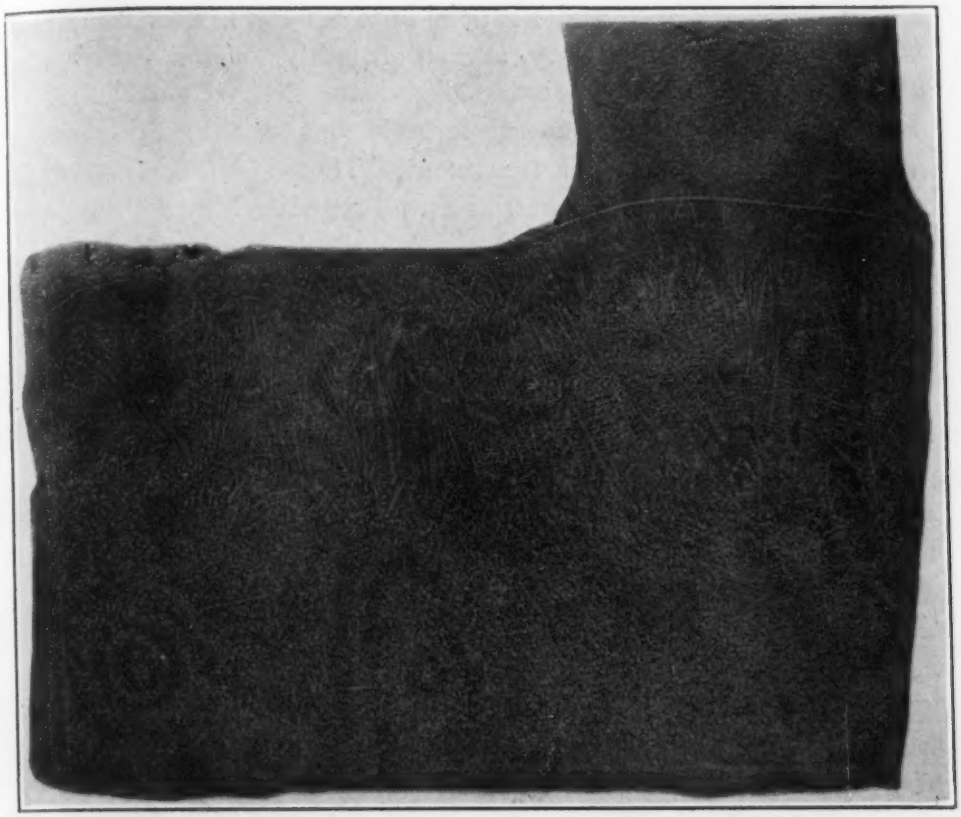

Fig. 5—Photomacrograph of Dendritic Structure of Cast Steel Revealed by Deep Etching. The Specimen was Photographed after Being Moistened with Glycerine. Although the Steel Casting was Annealed for 72 Hours at 900 Degrees Cent., the Original Dendritic Pattern Persists. The Distribution of the Impurities, Originally Located in the Angles Between the Dendrites, has not been Changed by the Treatment. × ½.

"burnt", i.e., there is incipient melting and the steel is ruined beyond hope of repair by any method of heat treatment. Burnt steel is of no use at all, unless as raw material to be remelted.

Good Heat Treatment a Precision Operation

So much steel is injured by annealing at, or quenching from, too high a temperature that one ought to try working as little above GOSK as possible. Bullens[6] recommends only 15 degrees Fahr. above GOS for hypoeutectoid carbon steels, and says that hypereutectoid steels have an even narrower permissible range than those of lower carbon. Many heat treaters allow somewhat greater leeway, but all agree in avoiding overheating as much as

[6]Bullens, D. K. "Steel and its Heat Treatment", third edition, 1927, pp. 48, 121, 189, 219.

is practicable. Camp and Francis[7] sum up the matter as follows, —"Heat slowly, uniformly and thoroughly *to the lowest temperature, and no higher,* that will give the desired results."

Williams and Homerberg[8] include this working rule among the fundamentals of heat treatment. They say "A few fundamental principles are followed in a well-regulated hardening plant. (1) heat slowly and uniformly, (2) *quench from as low a temperature as will be effective*—hypoeutectoid steel is quenched from 35 to 55 degrees Fahr. above Ac_3, eutectoid and hypereutectoid material from slightly above Ac_1, (3) cool evenly to prevent distortion, (4) avoid sharp or reentrant angles in the part to be quenched whenever possible, (5) temper immediately after hardening."

When we recall that the hardening is not complete unless we go above GOSE, and that we may get poorer results when we go as much as 15 degrees Fahr. above that line, two things are plain. We must know the position of the steel we are treating on the "chart" so we may know what the proper quenching temperature is, and we must have accurate pyrometric control. For plain carbon steel of more than about 0.35 per cent carbon the complete disappearance of magnetism coincides fairly closely with the reaching of a suitable temperature for quenching. Steel at a temperature at which it will attract a magnet is not hot enough for quenching, but after this temperature is passed the magnet tells nothing about the temperature and affords no check against over-heating.

Heating in an open fire and controlling the temperature by eye will not bring out the best results unless by pure accident. It certainly will not produce the best results consistently. Hence, the tendency in modern heat treatment is to analyze chemically and to sort the steel so that we are not really treating a 0.30 per cent carbon steel when we think we are treating a 0.40 per cent carbon steel. "Spark" tests and the appearance of the fracture are not sufficiently accurate criteria to be relied upon to show the carbon content. It is also necessary to check up the pyrometers constantly to be sure they are reading the true temperature, to be sure that the pyrometer is indicating the temperature of the work and not merely that of the furnace, and, wherever possible, to

[7]Camp, J. M. and Francis, C. B. —"The Making, Shaping and Treating of Steel", fourth edition, 1925, p. 680.

[8]Williams, R. S. and Homerberg, V. O.—"Principles of Metallography," second edition, 1928, p. 150.

control the furnace temperature automatically and move the work through the furnace, mechanically, on an exact schedule.

We must also be sure that the whole mass is uniformly heated so that no part is below the critical temperature. In order to be sure of this, it is, unfortunately, sometimes necessary to heat the corners and thin parts of an irregular piece hotter than we would like in order to be on the safe side. Slow and uniform heating will minimize this undesirable over-heating of the corners. Uniformity of heating is indicated when a piece resting on a furnace hearth is moved and the part of the hearth thus made visible is seen to be the same color as its surroundings.

Modern automobiles and aircraft are made possible by the use of heat treated steel. That their cost is as low as it is and their reliability as high is largely due to the exact control of the heat treating operation which guarantees that every part is given the properties desired, even though they are treated by mass production methods. The modern heat treating shop employs precision methods just as truly as the modern machine shop. The one no longer considers that it cannot control its temperatures to better than 50 degrees Fahr., just as the other no longer works only to sixty-fourths, but instead to thousandths and ten-thousandths of an inch. The need for precision in heat treating is great in regard to heating for quenching or annealing, and we shall see that it is also important in cooling and in tempering.

As has been stated, the general rule not to go far above the lines GOSK for carbon steels in heating for quenching, does not necessarily hold for alloy steels. The addition of some alloying elements raises, and of others lowers, the temperature of formation of austenite, so that for each alloy steel the lines GOSK have to be separately established. Moreover, some of the alloying elements slow down the rate of grain growth of austenite so that it is quite feasible to heat to temperatures that would ruin a carbon steel. Each alloy steel, therefore, requires its own special treatment, but the individual differences among them can best be explained and understood after the case of carbon steel has been studied.

Rate of Heating

We must remember that heat will flow from the outside of a piece of steel to the inside only at a definite maximum rate. If

we try to heat too fast we will not have the necessary uniformity of temperature; the outside, especially the corners, will be hot, and the inside cooler. Pushing the furnace too fast runs the danger of overheating the outside of the piece. Hence, the rate of heating will vary with the size of the piece and has to be slow, especially with large pieces. Since steel expands on heating, there is danger of irregularly shaped pieces warping or cracking if they are heated so fast that the whole piece does not expand uniformly.

The permissible rate of heating is variously expressed by different authorities. One states that for each inch of maximum thickness of cross section of a piece, it will require from half an hour to an hour to heat safely to the proper temperature and then hold that temperature for a sufficient time to bring about the proper diffusion of carbon. Another says that, for each inch of maximum thickness of cross section, it should take a quarter of an hour for a cube and half an hour for a bar to heat *to* temperature, followed by holding *at* temperature, for diffusion, for half an hour for the cube and one hour for the bar, i.e., a 4-inch cube should be heated up in one hour and then held two hours, while a long bar 4 inches round or square should be heated up in two hours and held four hours. Still another expresses it that heat penetrates at the rate of ⅛ inch in five minutes and that steel can be heated at the rate of 30 pounds per square foot of furnace hearth area per hour for normalizing and at 60 pounds per square foot per hour for annealing.

The rate of heating and the time at heat must be based on the thickest cross section of the piece to be heated. Pieces with thick and thin parts must be heated especially slowly so as to reduce expansion stresses, the maximum temperature must not be so high as to overheat the thin sections, and the piece must be held at temperature long enough for proper diffusion of carbon in the thickest part which comes up to temperature the last.

The American Society for Steel Treating recommends the following rate of heating:

For carbon steels of 0.10 to 0.50 per cent carbon, heat one hour for every inch of diameter of thickness and hold at the required temperature for at least one-fifth of the time required for heating.

For carbon tool steels—0.65 to 1.25 per cent carbon—as follows:

Cross Sections—Weight and Time

Thickness of largest section of unit	Weight of unit pounds (approximate)	Time of heating in hrs. (approx.)	Time of holding in hrs. (approx.)
Up to and including 1 inch	Up to 100	¾	½
Over 1 inch and including 2 inches	Over 100 and including 300	1 ¼	½
Over 2 inches and including 3 inches	Over 300 and including 500	1 ¾	¾
Over 3 inches and including 4 inches	Over 500 and including 1000	2 ¼	1
Over 4 inches and including 5 inches	Over 1000 and including 1500	2 ¾	1
Over 5 inches and including 8 inches	Over 1500 and including 2000	3 ½	1 ½

Furnace Atmosphere

The furnace atmosphere is also important. If it is oxidizing we may get heavy scale. For quenching, even slight oxidation may be harmful, as a thin, adhering scale will prevent proper contact of the quenching medium with the steel. A thicker one may fly off during the quench and thus be less harmful in this respect at least.

To avoid oxidation, gas and oil flames should be run slightly on the reducing, or smoky side. In electric furnace heating, illuminating gas may be led into the furnace so as to exclude air, or charcoal placed near the door to combine with the entering air. The work may be packed in sand, lime, flake mica, cast iron chips, or in charcoal to prevent access of air. Control of the furnace atmosphere is desirable so as to avoid highly oxidizing atmospheres and the consequent scaling of the work. If a piece of pine wood placed in the furnace chamber blazes, the atmosphere is dangerously oxidizing. If it chars without blazing, the atmosphere will not cause much scaling.

Lead baths or salt baths give freedom from oxidation and good temperature control, however, the work should be preheated before placing in a fused bath that is at a high temperature, to avoid the too rapid expansion of an irregularly shaped piece.

CHAPTER III

Annealing and Normalizing

Stress-Release in and Recrystallization of Cold-Worked Steel

A steel which has not been hardened by quenching, but has

been worked cold, by rolling, hammering, stamping, spinning, drawing or similar operations, increases in hardness due to the cold work. Work-hardening involving severe deformation, such as is shown in Fig. 2G, is usually carried out on the steels low in carbon.

A deep-drawing or stamping operation can be carried only just so far before the steel will have no more ability to be deformed and will crack; it has become brittle. Even if it has not been deformed to the limit, internal stress will have been introduced and the steel will have lost ductility and toughness while gaining strength. Toughness and the ability for further deformation without cracking can be regained by heating. Heating to the temperature at which austenite forms, of course, changes the entire structure of the steel, and is a part of the operation of true annealing. Either true annealing, or a lower temperature anneal is carried out between different stages of a cold working operation, as often as is required to restore the ability to be deformed. But one often wishes to preserve in the finished piece some of the strength and hardness that have been gained by cold working, and to restore some of the toughness, without bringing the steel completely back to its original softness. It may be desired only to relieve some of the internal stress and thus decrease the tendency toward warping which obtains in a cold-worked steel.

These objects may be accomplished by heating the steel below the line PSK, Fig. 3. Steel at elevated temperatures becomes plastic and less stiff. The crystalline grains that have been mashed out of their original shape by cold working (into plates in rolling a sheet and into threads in drawing a wire) would like to spring back so that each bent particle can straighten out, but the cold steel is too stiff to allow relative motion of the grains. As the steel is heated up, these grains are not held so tightly by their neighbors and tiny motion of the grains is possible within the steel. Thus, the internal stress is more and more relieved as the time and temperature of heating are increased. Such a low temperature heating process is sometimes, though rarely, called "blueing" (because if done in air a blue temper color may appear). The term "process annealing" is more generally used, and, especially for heating to temperatures not far below the line PSK, the unmodified term "annealing" is also often used to refer to this

process as well as to true annealing. The low temperature heating is sometimes called "shop annealing", "works annealing", or "white annealing", especially in reference to cold rolled sheet, like tin plate.

Up to about 600 degrees Fahr. for most steels, all that the heating does is to relieve internal stress by allowing slight motion of the grains, with relatively little effect on the strength and ductility. The proportional limit is raised and the tendency to warp decreased. Around 675 degrees Fahr. the treatment may cause "blue brittleness" and actually decrease the toughness. Around 750 degrees Fahr. the ductility begins to increase markedly and the strength to drop. Somewhere between 930 to 1065 degrees Fahr., usually at 975 degrees Fahr., this behavior becomes very marked; the microscope will indicate that at this temperature the grains which had been stretched out and broken up by cold working, start to *recrystallize,* the deformed grains first splitting into tiny ones and these tiny ones then growing into larger ones. The new grains, instead of being elongated as the old ones were after cold working, are now about as long in one direction as in another (equiaxed). The ferrite grains recrystallize more readily than pearlite grains do and it is more difficult therefore, to anneal below the line PSK a steel containing considerable amount of pearlite—for example, 0.40 per cent carbon equivalent to 50 per cent pearlite—than a very low carbon steel where the structure is mostly ferrite. Three things are necessary for this recrystallization, a strained grain, the right temperature, and time. As in all cases of heating steel, once a proper temperature range has been reached, a shorter time at a slightly higher temperature gives about the same results as a longer time at the lower temperature so that one generally thinks of the time-temperature factor as really one, rather than two factors. (One does not get *crystallization* at ordinary temperatures through vibration or repeated stress, as is often wrongly stated to occur. Crystallization is not a correct term for a fatigue failure).

Steel recrystallized at the lower temperatures has not the complete softness and ductility that can be obtained by a full anneal, but as we approach the line PSK, i.e., 1350 degrees Fahr., the softness of a fully annealed steel is approached. This is natural for, as we shall see, steel recrystallized after cold working and

steel that has been through the full annealing process have somewhat similar microstructures. The rate of cooling after recrystallization is generally not important.

Full annealing involves cooling from above the line GOSK and in this case the rate of cooling is very important.

Cooling from Annealing Temperatures

We know that as we heat through the temperatures represented by the lines PSK, GOS and SE, changes take place. We should expect that the *reverse* changes would take place as we *cool* through those temperatures. If we cool *slowly enough,* we *do* get the reverse changes, but they occur at somewhat lower temperatures. Eutectoid steel changes from pearlite to austenite on heating at about 1350 degrees Fahr., but on slow cooling it changes from austenite back to pearlite at about 1310 degrees Fahr. If we increase the rate of cooling somewhat (but not too much), we may further depress the change temperature. Thus we have two diagrams, one to represent the changes on heating and another to represent those on cooling. This is shown in Fig. 6. The lines for changes on cooling are dotted to show that they are not fixed but vary with the rate of cooling.

Critical Points and their Relation to Annealing Temperatures and Cooling Rates

It is again necessary to find for these changes names or symbols that differentiate between heating and cooling. These "change points" or "critical points" are often referred to as transformations. Another term is "arrests" because the cooling is arrested when we get the halts in the cooling curve corresponding to the halts in the heating curve referred to on page 507. The symbol A is used for arrest. The initials of the French words for heating (*chauffage*) and cooling (*refroidissement*) furnish the symbols that differentiate the changes on heating and cooling. The initial *c* is used for heating and may be remembered as the initial of the English word *caloric* (pertaining to heat) while *r* is used for cooling, and may similarly be remembered as the initial of the English word *refrigeration.*[9]

[9]The critical points on cooling are sometimes called *recalescent* points because the steel stops cooling, i.e., heats up because of the energy liberated in the change at the critical point. Those on heating are sometimes called *decalescent* points.

Ac is then a change on *heating* and Ar one on *cooling*. To tell whether we are dealing with the change at PSK where pearlite changes, at MO (Fig. 6) where there is a small thermal change, or at GOS or SE, the changes on the low carbon end are numbered as we meet them on heating. Hence Ac_1 refers to heating through PSK; Ac_2 to heating through MO, Ac_3 to heating through GO, and Ac_{3-2} to heating through OS. The change of cementite at SE on heating is called Ac_{cm}. On cooling we have Ar_3 as we pass through G′O′, Ar_2 through MO′ (this point is the only point that is found at the same temperature on heating and cooling, and it plays no part in the heat treatment) Ar_{3-2} through O′S′, Ar_1 through P′S′K′ and Ar_{cm} through S′E′.

Ac_1 and Ar_1 are pearlite points; above them we have no pearlite. Ac_3 and Ar_3 are ferrite, and Ac_{cm} and Ar_{cm} are cementite points; above them we have none of these constituents, only austenite. *Between* Ac_1 and Ac_2 or Ar_3 and Ar_1 we have *both* ferrite and austenite; *between* Ac_1 and A_{cm} or A_{cm} and Ar_1 we have *both* cementite and austenite. This is shown in Fig. 7.

In commercial steel the critical *points* are really critical ranges because a small temperature range is required to complete the action instead of the action being completed at one exact temperature. Since the ranges are small, one usually speaks of critical points, especially as the term "critical range" is also applied to the whole temperature range between GOS and PS or SE and SK. The critical points are shown more clearly by special apparatus such as that used for their determination by the "inverse rate" method than they are on simple heating and cooling curves. The "halt" in a cooling curve is of the nature shown in the upper curve of Fig. 12, while the halts in the inverse rate method curves are shown in Fig. 8B, at the right.

As long as we cool sufficiently slowly through the Ar points we end with ferrite and pearlite, pearlite alone or pearlite and cementite, depending on whether the steel is hypoeutectoid, eutectoid or hypereutectoid. That is, slow cooling gives pearlite. In true annealing we want softness. Softness is obtained when the steel contains its carbon in the form of pearlite and when the ferrite of hypoeutectoid steels is coalesced into a complete network, all around the pearlite grains, so that the properties of the steel are chiefly dependent on the soft ferrite. If we cool *very slowly*

through the critical range the excess ferrite will show complete coalescence and the steel will have its maximum softness. As we come down from the austenite field in a 0.50 per cent carbon steel, for example, and are in the range between GOS and PS, the longer the time we allow, i. e., the slower the cooling during the precipitation of ferrite, the more it can agglomerate or coalesce before the remaining austenite changes to pearlite at PS. With more rapid cooling and ferrite formed before the pearlite is formed (proeutectoid ferrite) will have less chance to coalesce and will appear in smaller crystals, as a *fine* network around the austenite which is throwing ferrite out of solution as it cools. If we rush the cooling, not so much ferrite will be ejected to the austenite grain boundaries, and the remaining austenite will be lower in carbon when it reaches Ar_1 than with slower cooling.

Hence, with rather rapid cooling as in the air (i. e., "normalizing") much of the excess ferrite over that required to form pearlite is thrown out as fine grains uniformly mixed with the pearlite and only a thin network of ferrite outlines the position of the old austenite grains. With slower cooling, as in annealing, the ferrite separates more completely, the remaining austenite is richer in carbon and the pearlite formed is purer, less mixed with excess ferrite. The area of pure, pearlite-free ferrite is the greater, the slower the cooling through the transformation range. Once the temperature has fallen below PS the rate of cooling makes no difference, no structural changes take place (except in the spheroidizing range which will be discussed later, and with the possible exception of cooling through the line PN, Figs. 3 and 7, about which too little is known to allow comment).

Since the first ferrite thrown out of the austenite as it cools below GOS is at the surfaces of the austenite grains, large austenite grains produce a coarse network of soft, weak ferrite, like a mass of soft putty within which are hard pebbles or pearlite (mixed with ferrite). The smaller the austenite grains the less putty and the more pebbles there are, i. e., the mixture is much more uniform.

The physical properties of the uniform mixture are better than those of the non-uniform one, hence small austenite grains are desired and this need for small austenite grains is the reason for not raising the temperature far above GOS.

In selecting the proper temperature for heat treatment of a

particular steel it is necessary to remember that the different alloying elements exert different influences on the location of the critical points, and that even in carbon steels quite small variations in carbon content and moderately small one in manganese and silicon affect them. Nickel has a very decided effect in lowering the critical points and on account of the commonness of nickel steel scrap, a

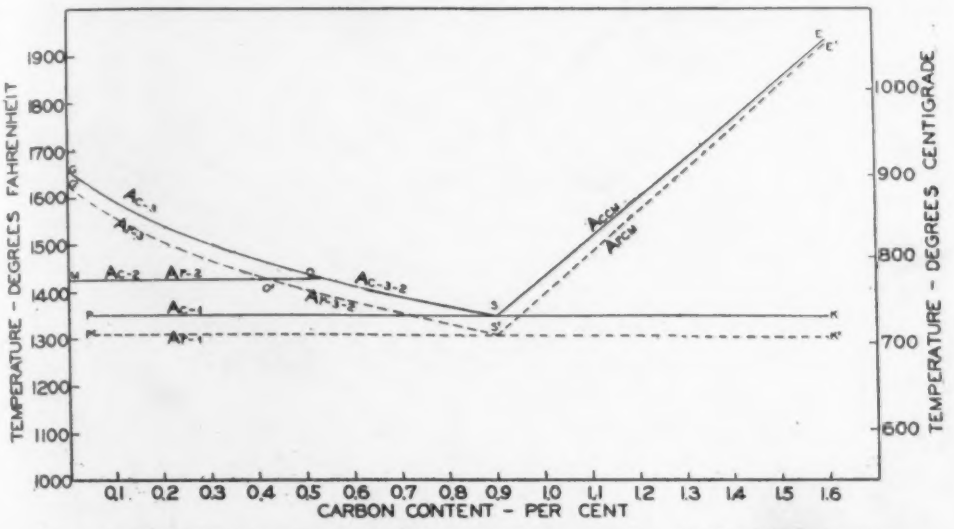

Fig. 6—Critical Points in Carbon Steel—Solid Lines, Heating—Dotted Lines, Cooling.

little nickel is generally present in many "carbon" steels to which it has not been intentionally added.

In order to know at just what temperature the end of the Ac_3 critical range (which must always be exceeded for annealing, normalizing or quenching for hardening) comes for a given steel, we must either (a) make a thermal analysis on that particular steel, (b) have a complete and accurate chemical analysis and compare the analysis with known Ac_3 end temperatures for steels of varying composition, or (c) heat a number of specimens of the steel, take out specimens at different temperatures, and quench them. The hardness will, except in extremely low carbon steels, show a sudden jump as Ac_1 is passed and increasing hardness as the quenching temperature rises to the end of Ac_3. The fracture will show the smallest grain size at about the best temperature for annealing, normalizing or quenching. As the temperature rises above the end of Ac_3 the grain size increases. Examination under the microscope will show the grain size more certainly than will the fracture. After the critical temperature has been found it then remains to

determine the proper time at the chosen temperature, which will be a little above the end of Ac_3.

Tensile tests or other mechanical tests may be used to determine the proper temperature. The method chosen will depend on the facilities available. A dilatometer, which registers the changes in rate of expansion of the steel on heating and cooling, will show the critical points in much the same way that thermal analysis does

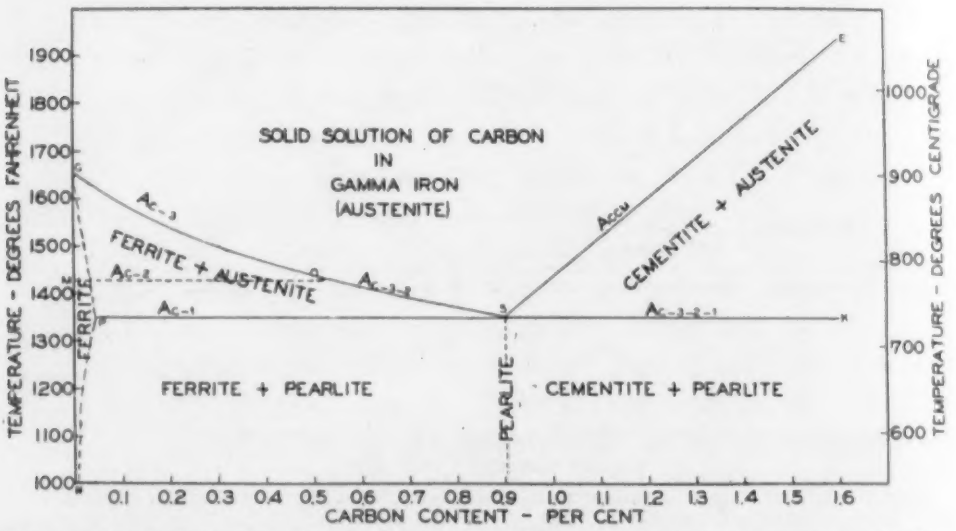

Fig. 7—Fields of the Iron-Carbon Diagram in Relation to the Critical Points on Heating.

(See Fig. 8B). Steels of over 0.40 per cent carbon lose their magnetism at a temperature practically the same as the end of the thermal critical range and a magnet may be used to find out if the steel has become austenitic, i.e., nonmagnetic.

In Fig. 9, 10 and 11 are shown the temperature ranges specified by various authorities for annealing, normalizing and quenching plain carbon steels. While the recommendations shown as blocks in Fig. 9 might literally be interpreted as shown, the real intent is to change the temperature with the composition, and the shaded band is the best guide. In the blocks showing annealing temperatures for steel castings, for example, the upper temperature 1525 degrees Fahr. is for a 0.65 per cent carbon steel and the lower, 1465 degrees Fahr. for one of 0.80 per cent carbon. Hence it will be seen that all these recommendations can be summed up into the simple statements that, for normalizing, annealing and quenching, a steel of less than 0.90 per cent carbon should be heated slightly above the end of the Ac_3 range (the line GOS) so that it all becomes

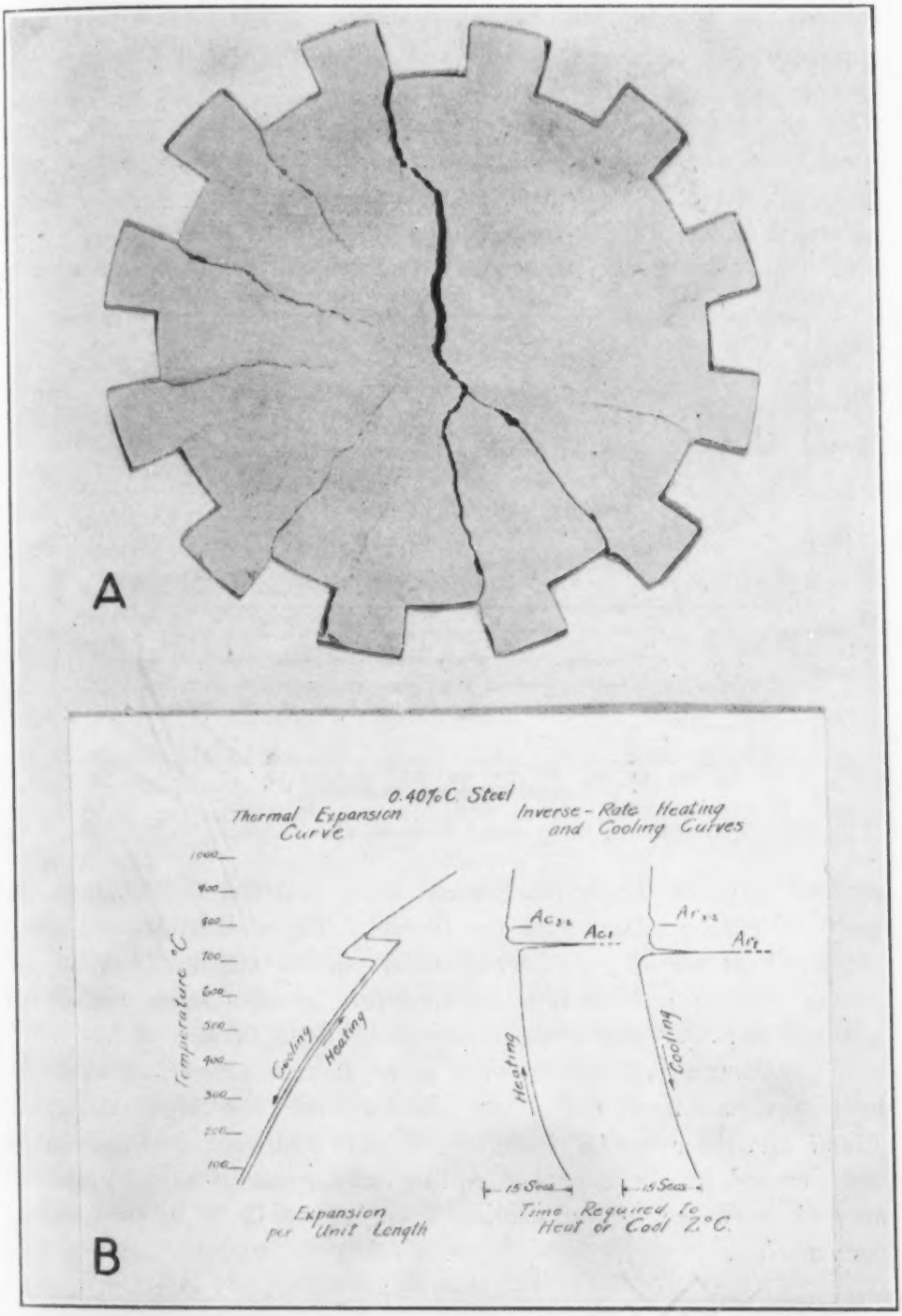

Fig. 8—Effect of Sharp Angles in Quenching; Cracks in a Splined Shaft. The Cracks (a) Start at the Sharp Angles. The Quench was too Drastic for such a Specimen. (b) Chart Showing Critical Points in 0.40 Per Cent Carbon Steel. As Shown, the Transformation Points Occur in the Same Temperature Range in the Thermal Expansion Curves as in the Inverse Rate Thermal Curves.

austenite. For the higher carbon steels, normalizing is done from just above Ac_{cm} (the line SE) and annealing and quenching from just above $Ac_{1\text{-}2\text{-}3}$ (the line SK).

Since it is desirable not to have the coarse network of ferrite that results from big austenite grains, the temperature is kept only a little above GOS. Whatever rate of cooling is to be used thereafter, it is desirable to start with a fine-grained austenite.

The properties of the cooled steel are controlled by the rate of

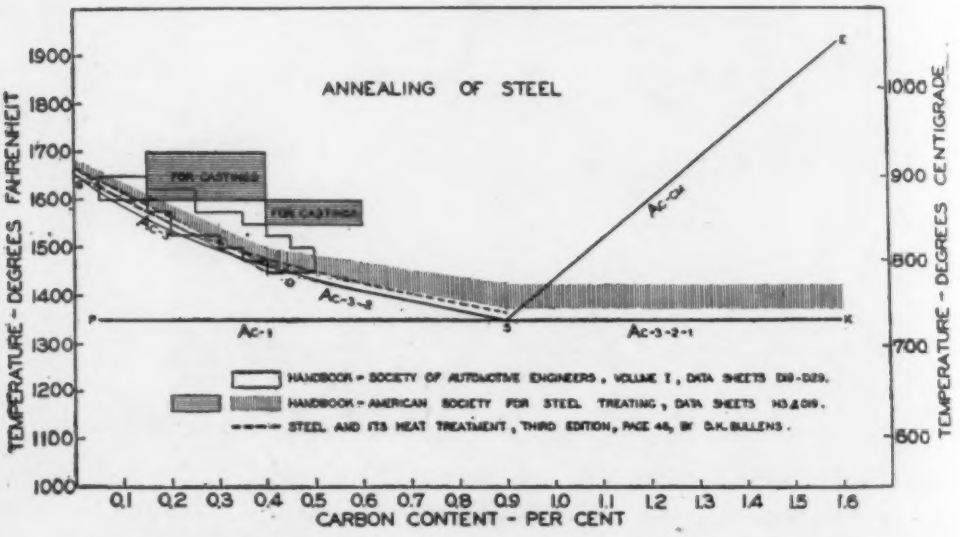

Fig. 9—Chart Showing Recommended Temperatures for Annealing Carbon Steels.

cooling through the critical range since this determines how the pearlite will be mixed with the ferrite. The slowest cooling gives coalesced masses of pure ferrite, interspersed with large masses of nearly pure pearlite. Less slow cooling gives smaller masses of pearlite and narrower areas of ferrite between them.

The coarser structure with more ferrite areas unbroken by pearlite comes from the slower cooling while the more uniformly mixed structure comes from the faster cooling. Ordinary-sized stock cooled in air after hot rolling or forging is said to have a *normal* structure. Air cooling from above GOS is then called *normalizing*.

Normalizing for Grain Refinement

We have seen that in the annealing of cold-worked steel, grain growth occurs as we approach Ac_1 on heating. The strength of

coarse-grained steel is not as high as that of fine-grained steel. To get a finer grain, advantage is taken of the ability of the steel to recrystallize as it passes through the Ac_1—Ac_3 and Ar_3—Ar_1 ranges. If it is taken above Ac_3 (or Ac_{cm} in a hypereutectoid steel) so as to be wholly converted into austenite, the original coarse structure is wiped out. On cooling through Ar_1 the steel changes to ferrite and pearlite (or pearlite and cementite in a hypereutectoid steel), thus recrystallizing. If the heating is not so far above Ac_3

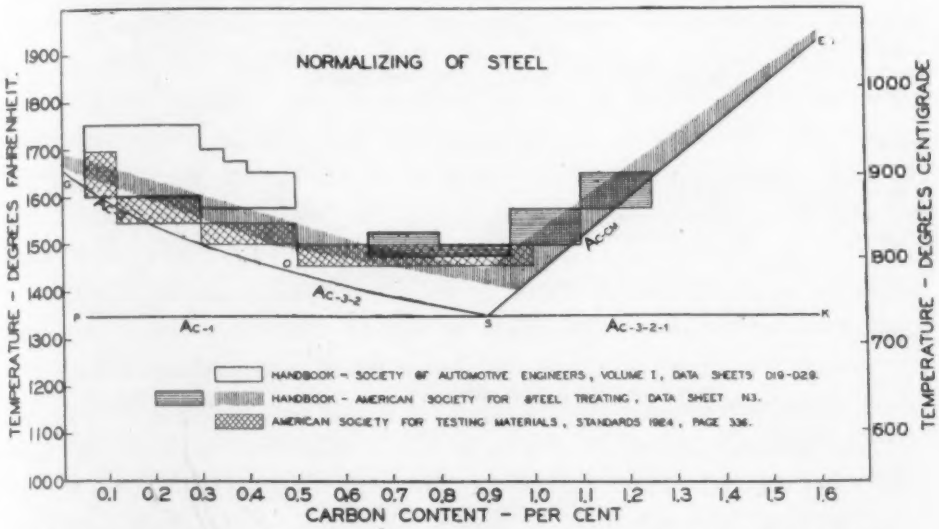

Fig. 10—Chart Showing Recommended Temperatures for Normalizing Carbon Steels.

or Ac_{cm} that the austenite grows into large grains, and if the cooling through the Ar_3—Ar_1 or Ar_{cm}—Ar_1 range is sufficiently rapid the resulting structure is fine-grained. This is shown in Fig. 4B.

Air cooling gives a suitable rate of cooling to bring about this grain-refinement in most carbon steels. The simple operation of normalizing may be used (1) to obliterate the cold-worked structure and the hardness due to cold work, (2) to produce a certain range of mechanical properties which may be desired for structural purposes (3) to refine the grain as a preliminary operation before reheating for quenching.

Air cooling of a large mass of steel castings, as when a car loaded with a couple of tons of castings is pulled out of the furnace above the critical temperature, gives a rate of cooling intermediate between furnace cooling and air cooling of a single small piece. Such normalizing is often used to refine the structure of cast steel.

By circulating the air, as with a fan, a more rapid rate of cooling is obtained than in still air.

True Annealing

If we want to get a softer structure, we retard the cooling by letting the steel cool down with the furnace in which it has been heated, or by covering it with sand, ashes or some such heat in-

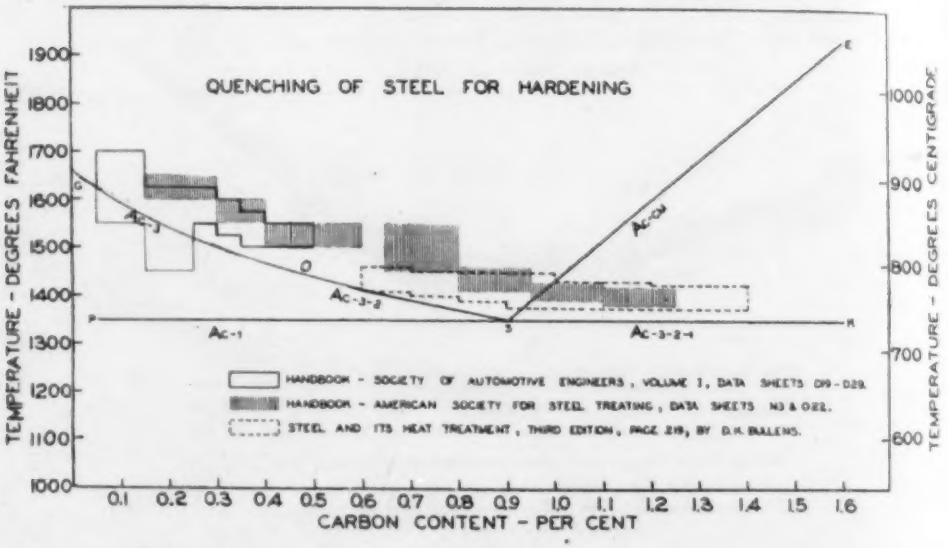

Fig. 11—Chart Showing Recommended Temperatures for Quenching Carbon Steels.

sulator to slow down the cooling. True annealing then involves both heating above the critical range, into the austenite field, and *slow cooling*. This gives great softness and relatively coarse grain —a proper condition for some types of machining because the tougher pearlite is massed together and the tool meets much ferrite free from pearlite. The more pure ferrite areas we have, the less difficult is the machining (down to the point where the steel begins to act "gummy.")

Spheroidizing

In the higher carbon ranges improved properties for some machining operations can be gained by still further fostering the creation of pure ferrite areas. It will be remembered that pearlite is itself an intimate mixture, in proportions corresponding to the eutectoid composition, of layers of ferrite and cementite. If we allow the cementite to agglomerate and collect into balls instead

of in plates or layers there will be a greater area of pure ferrite and machining will be facilitated.

The cementite in pearlite will break away from its sheet-like arrangement and ball up, or "*spheroidize*" or "*globularize*," into a structure like that shown in Fig. 4C if it is heated for a long time at the highest temperature at which it can exist, i.e., just below PSK. Free cementite of a hypereutectoid steel will ball up in the same way if given time just below PSK. Spheroidizing is more generally applied to the higher carbon steels. Those low in carbon have enough free ferrite so that spheroidizing is less essential, but any steel containing free cementite or much pearlite can be made softer and more ductile if a spheroidizing is given after annealing. For example, a eutectoid steel after a true anneal, may have a Brinell hardness number of 225. By spheroidizing, its hardness number is reduced to 165.

Spheroidizing may be applied to any steel containing cementite (iron carbide) or similar carbides in the alloy steels, whether it be cold-worked, annealed, normalized, or quenched and tempered.

Spheroidizing requires a very long time and a temperature as little below Ac_1 as possible. It is often hastened by heating the steel a very little above Ac_1 for a short time, so as to take into solution in a little austenite some of the smaller particles of cementite that are too far away from the nuclei on which the globules are growing, and then, by cooling just below Ar_1, to precipitate the cementite or pearlite again. If the initial pearlite or cementite is too coarse, going just above Ac_1, but not above and not too close to Ac_3 or Ac_{cm}, may be required to form the nuclei which are needed to start the formation of the globules, but after it is once initiated the essential in spheroidizing is heating just below PSK (Ac_1). From the separation of cementite that takes place in spheroidizing it is often called "divorce annealing." This is often applied to razor blades. On very high carbon steels, especially if the silicon is also high, this long annealing may tend to break up the cementite, splitting it into iron and carbon, the carbon coming out in the graphitic form in which free carbon is found in cast iron. The presence of a little chromium will prevent this decomposition. This graphitization is very rarely met in the heat treatment of steel, but is worth mention here to bring out the fact that steel, cast iron and malleable iron, (all alloys of iron and

carbon), differ in that in the irons graphite normally occurs while it is very abnormal to find it in steel. There is a second equilibrium diagram for the iron-graphite alloys which is described in the larger text books, but it does not have to be considered in the normal heat treatment of steel.

Annealing Steel Castings

The principles involved in the various kinds of annealing for relieving internal stress, softening and toughening and promoting machinability having been discussed, it remains only to consider the special case of the heat treatment of steel castings. This differs from that of wrought steel because of the different initial structure. The structure of the ingot from which steel is rolled or forged has been broken up by hot working, by air cooling from the forging temperature, and perhaps also by cold working. Wrought steel thus has a very different initial structure from that of cast steel.

Cast steel, especially in large masses which freeze slowly is very prone to have a coarse, *dendritic* (pine tree) structure (Fig. 5) which tends to make the casting brittle. The needles which freeze first and form the axes of the trunks and branches of the dendrites are surrounded by material of higher carbon content, and the non-metallic impurities that are the last to freeze or that are pushed out as the crystal forms, make up a sort of skin about the dendrite. As the frozen metal cools in the mold it necessarily has to cool through the austenite field. It has already been pointed out that cooling austenite from a high temperature results in coarse grain and brittle structure, so in a casting we have an exaggerated case of (unavoidable) overheating of austenite, compared to the temperatures used in heat treating wrought steel. It is necessary to destroy this large grain structure. If we could forge it and break up the large grains and thus reduce the distance over which diffusion must take place the subsequent heat treatment could be carried out normally, but this is, of course, not done to a casting. The austenite of cast steel heated only a trifle above GOS is initially so non-uniform in carbon content, and the non-metallic inclusions are so localized into a barrier against diffusion, that a very much longer time and a much higher temperature are required than is the case with wrought steel. (See Fig. 9.)

(Screw stock, which contains many manganese sulphide in-

clusions, intentionally present so as to break up the chip in machining, is similarly difficult to anneal.)

In cast steel the necessity for diffusion over-balances the danger of grain growth. A one inch square bar of 0.25 per cent carbon wrought steel would generally be annealed at about 1550 degrees Fahr. for half an hour or an hour, while if it were of a similar cast steel it would be annealed at from 1650 to 1700 degrees Fahr. for two to four hours. If the piece were a much larger cross section of wrought steel it would be heated longer than the small section would be, but not at a very much higher temperature, while a large casting might have to be heated to 1800 or 1900 degrees Fahr. for twenty-four hours before the austenite became sufficiently homogeneous for a good structure to result on cooling through the critical range.

Very large forgings, which are not much reduced from the ingot size in forging and whose original dendritic ingot structure is not thoroughly broken up, offer much the same difficulties as castings and have to be handled much the same as to annealing temperatures.

Castings often have thick and thin sections so arranged that warping and cracking ensue if cooling is too rapid. Normalizing is applied to castings to give different properties from those obtained by annealing, or for preliminary grain refinement prior to an annealing or a tempering operation, but quenching and tempering are seldom applied, never to very large or intricate castings. True annealing, involving very slow cooling in the furnace between Ar_3 and Ar_1, is the heat treatment usually applied to steel castings, although air cooling a large mass of castings is often used instead of furnace cooling. This normalizing treatment may be followed by tempering.

Rate of Cooling in Normalizing

On page 527 the difference has been brought out between a retarded cooling, that allows coalescence of the ferrite of a hypoeutectoid steel, and a more rapid cooling, that gives a finer grain and a more intimate mixture of ferrite and pearlite. Except in steel castings, annealed material is seldom used for structural purposes, because of their inferior strength. When strength is wanted, we may have to anneal to make the steel machinable, and after

machining restore the strength by some heat treatment involving more rapid cooling. Structural steel is used in the normalized, not the annealed condition, for most bridge and building construction.

In a steel of given carbon content and given cross section, the rate of cooling resulting from taking the steel from the furnace above the Ac_3 point and allowing it to cool in still air is fairly definite and reproducible. This "normalizing" treatment is often used as a preliminary to a true anneal (the combined treatment being sometimes termed a "double anneal") or to quenching and tempering. It plays somewhat the same rôle in grain refinement as hot working does.

The operation of normalizing cools the steel rapidly through the region of changes between GOS and PS or SE and SK, Fig. 3, and tends to prevent those changes, that would go on in slow cooling, from going to completion. It is naturally not very effective in the low carbon steels because of the great distance between GOS and PS; hence, in a 0.10 per cent carbon steel there is not much difference between a normalized and an annealed steel. But in forging steels, of say, 0.40 per cent carbon, the normalized steel will have a finer grained structure and be much stronger. Normalizing is much used in large locomotive forgings that will not stand the stress of quenching but which need greater strength than is obtained in an annealed steel.

(To be continued in November issue of TRANSACTIONS*)*

INCLUSIONS IN IRON

*A Photomicrographic Study**

By C. R. Wohrman

CHAPTER V

GENERAL ASPECTS OF THE INCLUSION PROBLEM

1. *Purpose of the Chapter.*

STUDIES described in the preceding chapters have dealt with the major class of inclusions:

(1) The oxides (including silicates).
(2) The sulphides.
(3) The oxide-sulphides.

We have studied the details of these inclusions, notably in regard to their appearance, constitution and etching features. At the same time we have endeavored to look into their formation, behavior and peculiarities.

These studies, by necessity, were somewhat confined. They nevertheless warrant[30] some generalization which are of interest and of practical significance. It is the purpose of this chapter to present these general aspects of the inclusion problem, aspects which are to include not only such data as were provided by the present work, but also a brief examination of such theories, hypotheses and recommendations, as have gained widespread recognition and acceptance.

2. *What Do We Mean by "Inclusions"*

Inclusions have been defined as "substances mechanically entangled by the fused alloy" (50); and as "extraneous bodies held in a metallic mass which remained too short a time in a sufficiently fluid state to allow such inclusions to separate from the

[30]Inclusions present in commercial iron were found by the author to be quite similar to the corresponding types of artificially prepared inclusions.

*From a thesis by C. R. Wohrman submitted to Harvard University in partial fulfillment of the requirements for the degree of Doctor of Science in Metallurgy. The experiments were conducted in Professor Sauveur's laboratory. The paper has been divided into five chapters. Chapters I and II appeared in July, Chapter III in August and Chapter IV in September, 1928, issues of Transactions. Manuscript received January 4, 1928.

mass by reason of difference of density'' (57). These definitions are limited; they are, furthermore, encumbered by statements having a bearing on the mechanism of inclusion formation.

More frequently inclusions are classified as ''non-metallic or oxidized impurities'' in contradistinction to ''metallic impurities.''

The division of impurities into ''metallic'' and ''non-metallic[31]'' is hardly descriptive. It is, indeed, strange why carbon or phosphorus, for example, and even ''metalloids[32]'' should be classified as ''metallic'', and, on the other hand, why iron sulphide should be termed ''non-metallic''. It is further obscure why ''non-metallic'' should be synonymous with ''oxidized''.

The important distinction between ''metallic'' and ''non-metallic or oxidized'' impurities lies, [as is pointed out by Dr. Sauveur (58)], in the fact that the first form true alloys with the metal, while the second are associated with the metal in a purely mechanical way. ''Alloy-forming'' and ''mechanically included'' impurities would, accordingly, be more descriptive and appropriate terms for these classes.

Inclusions, by general consent, are impurities, i.e., elements or compounds which were not intended nor desired in the metal. They are, further, a special class of impurities, and namely those impurities which are associated mechanically with the metal at ordinary temperatures. A simple yet precise definition of inclusions is, therefore, as follows: *''inclusions or enclosures are impurities mechanically associated with the metal at ordinary temperatures.''*

3. *Sources of Inclusion-Forming Materials*

Views Generally Held. The principal inclusions encountered in iron and steel are oxides, silicates and sulphides. As a source of these inclusions furnace slag is mentioned most frequently (56, 57). The refractories of the furnace, the ladle lining, the runner brick, are also held to be responsible. Some believe that the reactions which take place in the metal bath and in the ladle are an important source (41, 58, 59).

C. H. Herty, Jr., (61) thinks that there are ''five possible sources of non-metallics in open-hearth practice:

[31]This division appears to have been introduced, first, by Heyn (22), p. 71.

[32]Heyn (58), p. 71.

(1) Non-metallic matter in or on the scrap charged.
(2) Non-metallic matter in the pig iron.
(3) Non-metallics formed when the pig iron is introduced into the open-hearth by the oxidation of the metalloids (?)[33] silicon, manganese, phosphorus and aluminum, and by the introduction of sulphur from the iron.
(4) Formation of non-metallic matter when the heat is worked with ore or pig iron.
(5) Formation of non-metallics when the final additions are made."

It cannot be denied that the original inclusions in the pig iron and scrap may, partly at least, contribute to the inclusions of the metal made from these materials. It appears, however, that inclusions from this source are altogether negligible. Indeed, what can be the significance of a few pounds of oxide inclusions delivered into the bath with the scrap, when tons of iron oxide, each particle of which is a "non-metallic," are charged into the same bath in the form of ore?

The brickwork in and about the furnace is a more serious source but even this source is one of subordinate importance since it yields only accidental inclusions. The same can be said about the slag blanket.

Fundamental Sources. As the author sees it there are but two important fundamental sources of inclusions:

(1) The oxygen introduced into the metal bath with the ore and from the atmosphere.
(2) The sulphur introduced with the charge and furnace gases.

In the absence of sulphur and oxygen there could form neither sulphides, nor oxides, nor silicates, and hence there would be no inclusions. It is possible, although, perhaps, not feasible economically, to use materials and a fuel free from sulphur. This would automatically eliminate sulphides.

It is not possible, however, to dispense with the oxygen, since oxidation is the very basis of present methods of iron and steel making, the fundamental mechanism of refining. As long as

[33] Questioned by the present author.

oxygen is present, iron oxide will be present as well as the oxides of silicon, manganese and other oxide-forming elements. And, consequently, oxide and silicate inclusions will be present. To recapitulate:

Fundamental sources of inclusions are:

(1) Oxygen } introduced into the metal bath through
(2) Sulphur } the charge and the furnace atmosphere.

Subordinate sources are:

(1) The slag in contact with the metal.
(2) The refractories in and about the furnace.

4. Status of Inclusions in the Molten Metal and Their Formation

Knowledge of the ways in which inclusions are formed and of the manner in which they occur in the molten metal is a prerequisite to a rational solution of the problem of inclusion elimination (62, 63). No treatment that can be given to a solid metal is capable of removing the inclusions from it;—this removal has to be accomplished before the metal solidifies.

What is the status of inclusions in the molten metal? Do we have here actual inclusions suspended in the viscous liquid or emulsified in it, or have we but potential inclusions, dissolved in the metal? According to Ziegler (36) the inclusions are not only in solution in the liquid metal but even in solid gamma iron. This view is an extreme one and has not been favored by others. By far the greater number of metallurgists are inclined to believe that inclusions are insoluble even in the liquid metal.

To quote *Giolitti* (57):

> "The more persistent, and to us more interesting emulsified sonims are attributed by a very well founded hypothesis to an origin in phenomena similar to those occurring in aqueous suspensions of finely divided bodies, or, more precisely, in true emulsions, formed by minute drops of a more or less viscous liquid suspended in another liquid with which the former cannot mix."

McCance (41) "is not aware of any facts . . . which would support the suggestion of solubility in steel of inclusions," and he thinks that "their practical importance is concerned with their existence as suspensions."

What is the evidence on which the foregoing conclusions are based? Ziegler merely shows that his hypothesis serves to explain

many phenomena observed in the crystallization of gamma and alpha iron. His conclusions appear largely unsupported. Giolitti does not give the details of his reasons for believing inclusions to be "emulsified". He points out, however, that the slag blanket comes into being from reaction products of the charge, globules of slag being formed here and there in the bath and collecting to form the slag. It is entirely feasible, therefore, that portions of "slag" thus formed are emulsified in the boil-period of the charge and are retained by the metal.

McCance assures himself first "that particles of 1/1000 centimeter diameter have practically no chance of reaching the surface" and that, in a typical case the percentage of entrapped particles would be about as follows:

Diameter of Particles in Centimeters	Per Cent Entrapped
All over 3.0×10^{-3}	0
All over 2.0×10^{-3}	54
All over 1.0×10^{-3}	88
All under 0.5×10^{-3}	100

The hypothesis of inclusion suspensions in the liquid metal is, therefore, tenable. McCance, next, shows that a high temperature of casting has been found to promote freedom from inclusions—a fact which can be explained satisfactorily only on the basis of the suspension hypothesis.

Solubility of Inclusions vs. Their Existence as Suspensions

It can hardly be doubted that a considerable proportion of the inclusions found in metals have originated in the manner suggested by Giolitti and McCance. On the other hand, no positive evidence has ever been presented that would refute the existence of potential inclusions in solution in their liquid metal.

The writer has shown, in preceding chapters, that iron oxide and iron sulphide are soluble in molten iron, and that oxides and sulphides contaminated by manganese are also soluble, at least to a certain extent. The solubility of FeO in iron has been demonstrated earlier by Tritton and Hanson (90), and that of FeS by Treitschke and Tammann (23), and Friedrich (50). Theoretical considerations of the equilibrium relations that exist in steel mak-

ing have been shown to support the contention of a limited solubility in iron of inclusion-forming materials.

Some of the advocates of the suspension theory admit themselves, at times, the solubility of "non-metallics" in liquid iron. Thus McCance (41) is found to state: "All the evidence is favorable to the view that FeO is in solution in liquid steel." . . . "The more correct explanation of the prevention of sulphur red shortness by manganese is based on the fact that FeS is soluble in liquid steel and separates out as an easily fusible eutectic."

Apparently the suspension mechanism is reserved primarily for silicates and manganese-bearing sulphides and oxides. These are perhaps, the only inclusions likely to occur in ordinary steel; it is equally true that they represent the only compounds for which solubility in steel has not as yet been proved directly.[34]

The experiments of the author indicate strongly that a considerable proportion of even these inclusions is actually dissolved in liquid iron. It will be remembered that in most of the experimental melts the inclusion-forming material was allowed to fuse quietly inside of an iron container. No agitation, no stirring was resorted to that could have "emulsified" the inclusion-forming material, or have caused its uniform distribution throughout the metal. To the contrary, all facilities were provided for the molten inclusion charge to float bodily to the top of the melt if it desired to do so. And yet no such separation took place except in the case of MnS, and even here it occurred to a limited extent only. Instead we found the mechanically included material to be distributed more or less uniformly throughout the metal—to have dispersed, in fact, instead of agglomerated. What mechanism other than dissolution could have accomplished this?

We must be careful, however, in judging true solubility by the number and size of inclusions found in the specimens referred to. The number and size of inclusions are not necessarily representative of their true solubility. For we may deal here with a diffusion phenomenon which of course implies solubility, but which can effect transfer of material in amounts quite independent of such solubility.

We must, further, bear in mind that the observations just discussed give us no information about the manner in which the in-

[34]FeO, for example, was held to be insoluble until proof to the contrary was offered.

clusion-forming matter is dissolved in the liquid iron. It may well be that ferrous oxide and sulphide are dissolved as such alongside with some silicon, manganese, carbon monoxide, hydrogen, etc., and that they react with some of these latter elements or compounds to form silicates, manganese sulphide, etc., only when the material begins to solidify. It may equally well be that FeO, as such, is not dissolved in iron, but is formed only as a reaction product, on solidification.

It may be argued that the melts of the author were too small to be representative of actual steel-making practice and that conclusions based on the behavior of these melts are, therefore, valueless. Such arguments have been advanced, in the past, on occasions similar to the present one. Their fallacy is obvious.

The size of the melt has nothing whatever to do with the problem. Conditions in which the melting operation was carried out are the only items that count. These conditions were not identical in all respects with those obtaining in practice; nor were they intended to be, inasmuch as it is futile to attempt to solve a complicated problem by involving oneself, at the outset, in a host of unknowns. The conditions were in their essentials, near enough to actual conditions to warrant taking the results as a first approximation to the final answer.

Evidence Furnished by the Size of Inclusions. Giolitti and Tavanti (64), in an attempt to disprove the solubility of inclusions in liquid steel, examined the size of inclusions, first in the metal quenched from the liquid state, and then in the same metal, annealed. They found no difference in the size of a given inclusion before and after annealing. This proves, of course, only that inclusions do not grow on annealing but remain as originally formed. It does not imply that they were insoluble in the liquid metal, for even drastic quenching does not necessarily prevent precipitation from solution.

In the writer's experience the inclusions in rapidly solidified metal are always considerably smaller than those in the same metal, slowly cooled, irrespective of the length of time the metal is kept molten. Does this not imply that growth of inclusions takes place primarily during solidification? And does not this, in turn, suggest that the inclusions, at least partly, are formed only on solidification?

In summarizing the evidence, it appears:

(1) that a considerable proportion of the inclusions found in iron and steel form prior to solidification, existing in the melt as suspensions or emulsions

(2) that an equally (if not more) important proportion is formed only on solidification of the metal, from materials dissolved in the molten metal

(3) that no inclusions of importance are formed after the solidification of the metal.

5. *Conditions Governing the Size, Shape and Distribution of Inclusions*

The size of inclusions of a given kind is governed primarily by conditions imposed upon the melt, after the final chemical reactions have taken place. The longer the melt is allowed to remain liquid, and the higher the temperature at which it is kept liquid the more opportunity is given for suspended immiscible globules to coagulate in the melt and to rise to the surface. The slower the solidification the more perfect will be the segregation into the last portions to solidify of such potential inclusions whose solubility limit is not reached even on manifold increase in concentration. The more pronounced will also be the "mechanical" segregation of such included matter as separates simultaneously with the first crystals of iron. It may be conceived that such matter, provided it remains liquid after separation from the iron, is pushed before the growing crystals of pure iron and brought together to form larger globules or pools. Quick solidification, on the other hand, will prevent both segregation and the mechanical collection of precipitated and suspended matter, which, accordingly, will appear in the form of finer inclusions, more evenly distributed.

The size of different kinds of inclusions, other conditions being equal, will be largely a function of their fluidity at the temperature of solidification of the metallic mass. The higher the fluidity of a given inclusion[35] the more readily it will escape from becoming entangled by the pasty iron, and the more readily it will join other inclusions. The reverse will be true of inclusions of high melting point. Their pasty condition will cause them to stick to the iron

[35]It must be noted that fluidity is a function of chemical composition, temperature and pressure. Gases liberated in the process of solidification may, locally, cause considerable pressure.

and stay where they were born. Even if several of such inclusions should meet they will show little, if any, tendency to coagulate. The number of inclusions, other things being equal, varies inversely as their size, and is, accordingly, governed, for a given amount of inclusion-forming material, by the same conditions that influence the size of inclusions.

The shape of inclusions, in cast metals, is generally spherical unless purely mechanical conditions interfere. Such mechanical conditions are responsible for the network or cell-wall structure exhibited by ferrous sulphide. Indeed, this sulphide is not only soluble in all proportions in liquid iron and is, therefore, easily segregated to the last portions to solidify, it also, (or its eutectic with iron) is characterized by a low melting point and hence great fluidity at temperatures when the iron crystals complete their growth. As a result this sulphide is forced into the interstices between the iron dendrites and is mechanically compelled to occupy the tiny openings in the fillings of the dendrites and the interdendritic boundaries.

While globular forms may be assumed by an inclusion solidifying either before or after the congealing of the metal, crystalline forms constitute, generally, evidence of solidification prior to that of the metal because only inclusions solidifying before the iron will be free to follow their crystallographic habits. Dendritic skeletons, such as were illustrated in Figs. 76-78 and in Fig. 83, are typical for such inclusions.

An inclusion whose melting point lies considerably higher than the temperature prevailing in its immediate neighborhood, at the time of its formation, will of necessity exhibit irregular outlines. The outlines of alumina inclusions depicted on Figs. 31 and 32 are an example.

A somewhat different type of irregularity will characterize "accidental" inclusions, such as are furnished by chips of the brickwork and other refractories which may find their way into the melt. The detailed outlines, here, will ordinarily be fairly smooth due to the partial fusion of the inclusion along the periphery—the shape of the inclusion as a whole will, however, be irregular.

The conclusions set forth above follow from a consideration of simple fundamentals of the physics and chemistry of inclusions. It is surprising, therefore, to find that even about these, apparently so obvious relationships there should be a difference of opinion.

The sulphide network, in particular, has received attention and has been attributed, by many, to a peculiar tendency of iron sulphide to "migrate" to "grain boundaries". Expressions like the above appear so universally accepted as representing the facts that a special study of the relationships between the sulphide network and grain boundaries was undertaken. It will be described later. Others have attributed this network to an unusual surface tension possessed by ferrous sulphide. In one case even the "infusibility" of FeS is blamed. To quote Greaves and Wrighton (65): "It (FeS) is very infusible and does not ball up like manganese sulphide—hence is injurious. . . "

Distribution—Minor Segregation. The distribution of inclusions in the metal is influenced by much the same conditions as govern their size and shape. Uniform distribution will be assisted by insolubility and the lack of fluidity of inclusions at the temperature of solidification of the metal, and by quick cooling. Solubility and fluidity, on the other hand, especially when assisted by slow cooling, will favor both the chemical segregation and the mechanical concentration of inclusions toward the peripheral regions of the metal dendrites.

Major Segregation. A systematic study of the distribution of inclusions in commerical ingots has yet to be undertaken. McCance (41) thinks that the ultimate position of inclusions in the ingot "is determined by secondary influences, or the laws of chance." He admits, however, that "some of the worst segregations . . . examined have come from the material between the center and the outside skin." Curiously enough, the present writer observed precisely the same phenomenon in his study of the distribution of inclusions in ingot iron; and found, furthermore, that there exists a distinct parallelism between the distribution of the inclusions and the occurrence of blow holes. This, surely, is not a coincidence, nor are the laws of chance responsible for this. The segregation observed is a direct consequence of the different conditions of cooling and of solidification (and of attendant differences in gas concentrations), prevailing in different parts of the ingot.

The relationships between the size, shape and distribution of inclusions on the one hand, and their relative fluidities, on the other, are admirably illustrated by the complete set of FeS-MnS inclu-

sions that where found to be present in the S-7 melt described. Compare, for example, the inclusions of Figs. 79 and 80. The inclusions of Fig. 79 are relatively rich in manganese and possess a melting point only slightly inferior to that of iron. Those of Fig. 80 remained fluid much longer. The former are small, the latter of substantial dimensions. The former, on the whole, are distributed fairly uniformly (see Fig. 81, region in the vicinity of the blow hole), the latter are located primarily in dendritic fillings (bottom regions of Fig. 81). Both are globular except where mechanical forces have come into play. Not so the inclusions of Figs. 76-78 representing crystallization prior to solidification of the metal.

Influence of Working. Hot working, as is well known, deforms such inclusions, as are plastic at the temperatures of working. These inclusions are elongated in the direction of work, the elongation, for a given amount of working, being the more marked the higher the temperature of working, the greater the plasticity of the inclusion at this temperature and the larger the size of the inclusion.

6. *Behavior of Inclusions*

We have briefly considered the formation of inclusions and have found that all important classes of inclusions come into being and assume an existence independent of the metal shortly after the solidification of the latter.

What is the behavior of inclusions in the solid metal?

(1) Are they undergoing any changes on annealing, quenching and other heat treatments given to the metal?

(2) Do such treatments induce inclusions to "migrate" in the metal?

(3) How does the preferential association of inclusions with ferrite and with cementite come about?

Heat Treatment and the Structure of Inclusions

The structure of inclusions, especially the complex ones, is, without doubt, affected by heat treatment. This has been demonstrated for the case of sulphide-oxide inclusions (Chapter IV), and there is no reason to believe that other inclusions will behave differently in this respect. Heat treatment affects the structure of all matter, in some cases more, in some less, and inclusions are, of course, no exception to this rule.

Heat Treatment and Changes in Size and Shape of Inclusions

That changes in size and shape of inclusions can be induced by heat treatment, is less obvious.

Opinions of Investigators. Giolitti and Tavanti (64) found that annealing of specimens of steel quenched from the liquid state had no effect on the size of the "slag inclusions" in their specimens; Steinberg (67), on the basis of similar experiments, concluded that inclusions of MnS and FeS grow on annealing.

McCance (68) describes heating a piece of mild steel "which was known to have numerous elongated inclusions" for some hours at 2190 degrees Fahr. (1200 degrees Cent.) and finding "that some of these elongated inclusions had broken up into numerous globules while others were quite intact and were just the same in appearance as prior to the treatment." . . . "This evidently," writes McCance, "was a case of the oxide inclusions going into solution, and subsequently becoming globularized in exactly the same manner as cementite at lower temperatures, while silicate inclusions or slag not being soluble were not affected."

McCance, it appears, did not examine the same spot before and after annealing, and his conclusions are, therefore, open to doubt. In another paper McCance (41) states that on heating sulphide bearing steel above 1795 degrees Fahr. (980 degrees Cent.) "the FeS would redissolve and diffuse into the surrounding steel."

Diffusion in Iron. A priori there is no reason why slight changes in the size and shape of inclusions should not be possible. Transfer of material in solids—segregation or diffusion—is, in fact, known to occur. Such segregation implies a certain solubility in the metal of the segregating element,—the segregation being effected, probably, by successive dissolution and precipitation of this element. Inclusions, generally speaking, are soluble in iron to a very limited extend only, at any rate at the temperatures ordinarily employed in heat treating: we would expect, therefore, segregation phenomena in inclusions to be very slight. And this appears to be the case, since no conclusive proof of such phenomena has ever been presented.

It is of interest, in this connection, to examine the diffusion velocities of some inclusion-forming materials. These diffusion velocities are a measure of the mobility, in the metal, of given constituents and, in a way, a measure of the solubility in the metal of

these constituents. As determined by Ziegler (69) the diffusion velocities for some of the common impurities are as follows:

Impurity	Speed of diffusion in microns per hour (at about 1300 degrees Cent.)
Manganese Sulphide	3
Mixture of manganese and iron sulphides	3 to 110 (average 70)
Iron sulphide	140
Carbon (carbide Fe_3C)	5700 (minimum) 8000 (more representative figure)

There is no doubt that many of the inclusion-forming compounds can introduce themselves into a solid metal by the process of diffusion, in much the same way as carbon does in cementation. This process, as is obvious from the above figures, is exceedingly slow even at temperatures which, ordinarily, are not employed in heat treating.

It furthermore, must be kept in mind that diffusion, while pronounced in a material free from the diffusing compound, is far less effective in a material already contaminated by that compound. And inclusion-bearing metals not only contain the compounds which are supposed to diffuse in them; these compounds had already all the opportunity to diffuse and to distribute themselves in a preferred way, at temperatures very much more favorable to diffusion than those employed in heat treating.

Reactions between Solids. Attention must also be given to the phenomena of reactions taking place in solids and between solid reagents. Such reactions are described by Tammann (70), Desch (71) and others (72, 73). But again it must be borne in mind that such reactions between solids as are indicated in metals, had ample opportunity to complete themselves at the high temperatures prevailing immediately after solidification, and that little, if any readjustments can be expected to take place at lower temperatures.

Conclusion. While changes in inclusions may be expected to take place on heat treatment, such changes appear, in general, to be entirely insignificant,—unless, indeed, the heat treatment used implies chemical changes. (Cementation, for example will destroy oxide inclusions, oxidation from oxy-sulphides, etc.)

Heat Treatment and "Migration" or Inclusions

If heat treatment is incapable of inducing significant changes in the immediate neighborhood of an inclusion, how can we expect such treatment to cause the migration of inclusions in the metal? Yet is not precisely this implied by statements often met with in the literature?

The following are but a few examples: R. S. Dean (65) writes: "... brittleness is greatly accentuated by the presence of considerable sulphur in relation to the manganese and also by annealing under oxidizing conditions, whereby an eutectic of FeS, Fe, FeO is formed which melts nearly 100 degrees below the Fe-FeS eutectic. Finally, by cooling rapidly, the segregation of these materials into the grain boundaries and consequent brittleness, may be prevented ... The rate of segregation of the impurities into the grain boundaries is important in determining the cooling rate necessary to prevent brittleness..." He, then, lists the diffusion velocities, at 2370 degrees Fahr. (1300 degrees Cent.), for MnS, FeS and Fe_3O_4 (should be FeO), given by Ziegler and concludes: "The difference between the diffusion velocities of MnS and FeS is striking and accounts for the greater slowness with which a high manganese ingot iron may be cooled without intercrystalline brittleness."

McCance (41) states that on heating steel above 1795 degrees Fahr. (980 degrees Cent.),—the eutectic temperature of Fe-FeS—"the FeS would redissolve and diffuse into the surrounding steel, and on cooling again below this temperature would not be redeposited in its original position, but would be deposited in between the crystal grains according to its habit."

G. Röhl (37), referring to the regularity of iron sulphide cell walls, writes: "The prominence of the symmetrical arrangement of the crystalline grains of the iron[36] is remarkable in connection with the higher percentages of iron sulphide."

Does Iron Sulphide Seek Grain Boundaries? It was conclusively shown in the preceding that the symmetrical arrangement of the sulphide envelopes is ascribable solely to their location in the dendritic fillings and the inter-dendritic spaces. (Chapter III). It was further shown (Chapter III) that ordinary heat treatment does not induce any detectable migration of the sulphide. And why should the sulphide seek to locate itself in the

[36]Rohl refers to his Fig. 2, which is similar to the author's Fig. 43.

boundaries of the crystalline grains of iron? It does so "according to its habit" writes McCance. Let us examine this habit.

Fig. 131, shows an unusually symmetrical group of sulphide cell walls supposedly located on the boundaries of individual iron grains. Yet etching (with 10 per cent HNO_3) indicates that they are located all within one single crystalline grain of iron. Fig. 132 illustrates the uniform attack by the acid of this single grain. This may not appear a satisfactory proof of the homogeneity of crystalline orientation. Let us examine, then, the orientation of the metal as revealed by etching pits visible at high magnifications. Fig. 133 shows them. They are seen to have the same orientation on different sides of the sulphide "boundaries", and, in fact, were observed to have the same orientation throughout the entire area pictured in Fig. 132.

What is the situation at the actual grain boundaries? Examine Fig. 134 which illustrates a typical spot of the sulphide specimen S-1. The actual grain boundaries are seen to be essentially independent of the sulphide stringers. Their details only, are affected by these sulphides. Observe, for example, the offsets in the lower grain boundary in Fig. 134, in places where it meets and crosses the sulphides. That the outlines of the crystalline grains of iron should be influenced by the preexisting sulphide stringers, to the extent shown, is quite in accord with what we would expect. The existing relationships are further described by Figs. 135 and 136. The manner in which a grain boundary line, bearing a right angle relationship to some sulphide walls, is seen to pass through these sulphides (cracking them locally) is especially interesting (Fig. 135).

A more detailed study of sulphide and grain boundary relationships which was undertaken by the author will not be described here. It served but to substantiate conclusions arrived at from common sense considerations.

The mechanism of sulphide distribution is governed by conditions of solidification of the metal. The number of the crystalline grains of the metal, their size and development, is a function of conditions prevailing subsequent to solidification, more specifically, of conditions below the Ar_3 point. Grain boundaries can be and are influenced by the sulphide only insofar as they interfere,

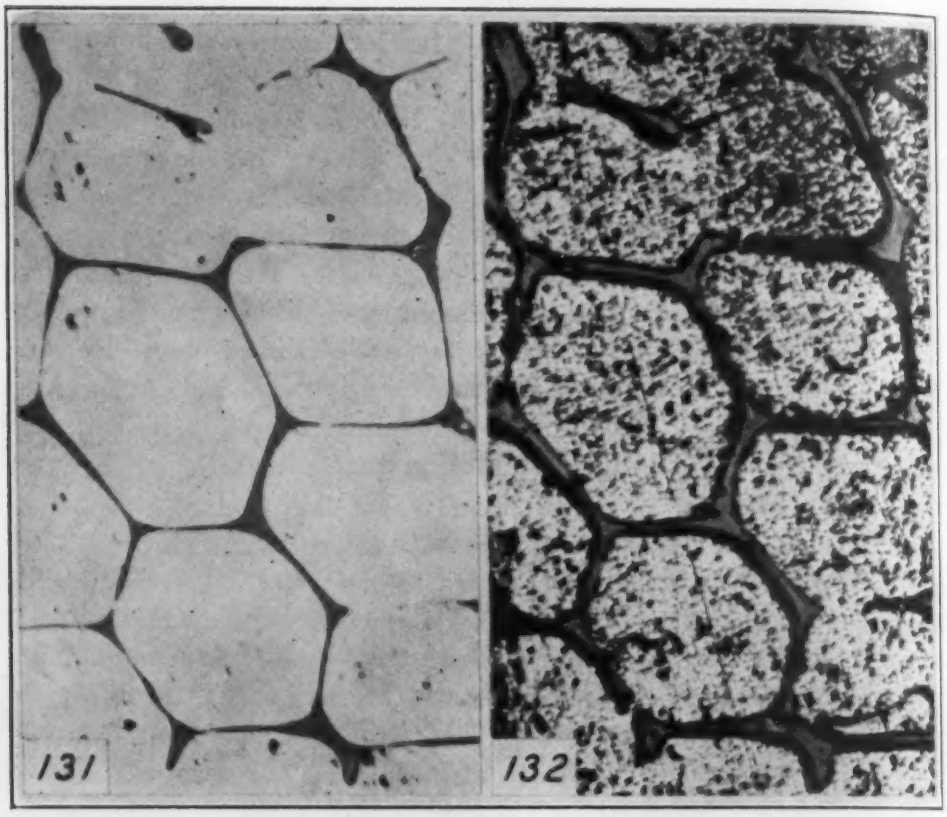

Fig. 131—A Group of Unusually Symmetrical Cell Walls of Iron Sulphide. (in S-1) × 300. Fig. 132—The Same Group After Etching with 10 Per Cent Alcoholic Nitric Acid. The Cells are Located within a Single Crystal Grain of Iron. × 300.

mechanieally, with their normal development. Why then the widespread notion of sulphide occurrence at grain boundaries?

The explanation appears simple enough. The first crystalline units or grains of a metal are the dendritic grains and it is at the boundaries of these grains, (and in the dendritic fillings), that the sulphide is located. Le Chatelier (16) had these primary grains in mind when he spoke of "a membrane around the crystallized grains of iron." Many later writers, recounting the findings of Le Chatelier and other early investigators, merely mentioned the fact of sulphide occurrence at grain boundaries thinking it superfluous to be more precise and specific.

Now, speaking about the crystalline grains of a metal we have in mind the existing crystalline grains and not the grains that were present in the metal months or, perhaps, years ago. Hence the confusion and the attempts to account for the existence of iron sul-

Fig. 133—Portions of Three Random Cells of Fig. 132. Etching Pits Prove the Identity in Crystalline Orientation of these Cells. Fig. 134—Grain Boundaries Fail to Follow the Sulphide. The Latter Modifies the Details of the Grain Boundaries. Note the Offsets in the Lower Boundary. × 100.

phide at "grain boundaries" by some process of migration or diffusion, or by just a mysterious "habit" of FeS. Another item which, undoubtedly, contributed to the confusion is the omission, already by early writers, of mentioning the dendritic fillings as a place of sulphide occurrence. Many of the regular meshes, outlined by sulphide, are cross sections of dendritic branches and not of the primary grains.

Conclusion

What has been said about the "migratory" habits of iron sulphide applies to other inclusions as well. Even more so, for these other inclusions are all less soluble in iron and diffuse with greater difficulty, with the exception, perhaps, of iron oxide. Inclusions are thus essentially fixed in solid iron and steel. They do not migrate.

The Preferential Association of Inclusions with Ferrite and Cementite

How can we account for the preferential association of inclusions with the ferrite of hypoeutectoid and the cementite of hypereutectoid steels? If the inclusions are fixed it is clearly the ferrite, resp. the cementite, that seek the inclusion bearing portions. Why?

According to M. Ziegler (36) the inclusions serve as nuclei for crystallization, producing an effect on solid solutions analogous to that produced by small particles of foreign matter in the crystallization of salts from liquid solutions. Ziegler thinks that the majority of inclusions are dissolved in solid gamma iron and precipitate on cooling, on the boundaries of the gamma grains producing thus an inclusion network. It is this inclusion network that the ferrite resp. cementite, is precipitated on when the Ar_3 (resp. Acm) point is passed. Hence the association.

H. M. Howe's reaction to this view point is worthy of being quoted in detail. He writes (74): "The common occurrence of slag within ferrite masses . . . is usually supposed to be caused by some attraction which the slag has for the ferrite. But by what piping does this Pied Piper entice the ferrite from within the austenite, draw it across considerable distances, and enwrap itself in it as in a garment? Why create so improbable an explana-

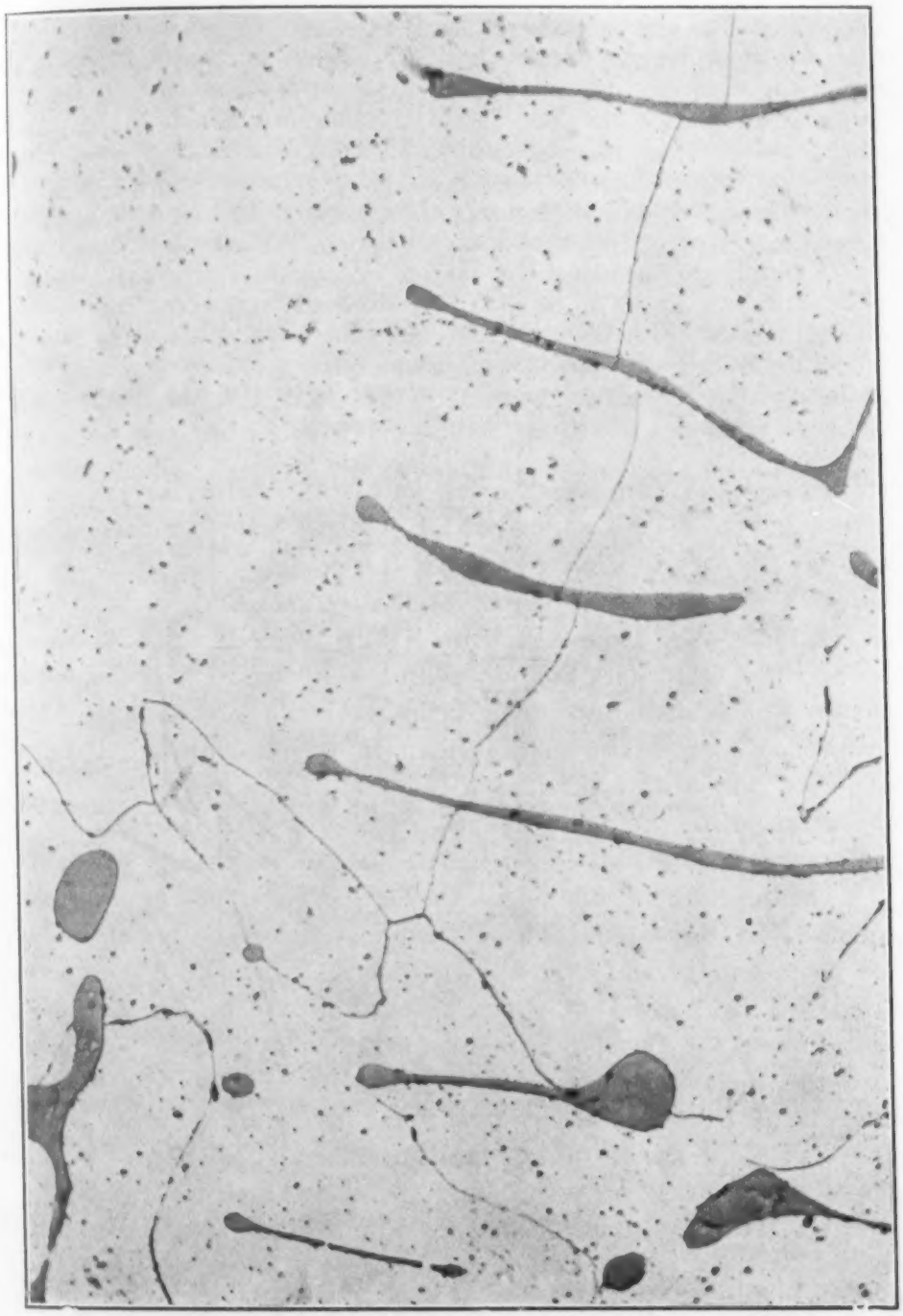

Fig. 135—S-1. Etched with 3 Per Cent Alcoholic Nitric Acid. The Grain Boundary Line is Offset Where it Crosses the Sulphides. Some of the Sulphides Appear to be Cracked Where the Grain Boundary Passes Through Them. × 500.

tion when the ejecting power of the austenite would lead to just this stratigraphic occurrence?. . . ."Each austenite grain is an organism with the power of expelling foreign matter to its surfaces and to its cleavages." "The austenite grains while above the transformation range would . . . . naturally dispose along their surface or their cleavages any slag which they contain. In later cooling through that range they arrange the proeutectoid element then born in like manner and hence this later arranged matter is found surrounding the earlier arranged slag, which itself is most unlikely to have any such power of arranging its disconnected masses geometrically. Because the crystalline power of the austenite is the only agent which can have arranged the slag thus geometrically, we infer reasonably that it is also the agent which has thus arranged the pro-eutectoid element."

Professor Howe, like Ziegler, holds that inclusions are soluble in the austenite. No experimental evidence has ever been offered for the support of this view. To the contrary, all evidence obtained shows inclusions to be essentially insoluble in solid iron. Apart from this, Professor Howe's hypothesis is open to serious doubt since inclusions are not found to occur in Widmanstätten patterns as is demanded by this hypothesis. Professor Howe is, however, consistent in advocating such an occurrence. If inclusions are soluble in solid iron they should come out of solution in a corresponding manner, i.e., in precisely the same manner as the other pro-eutectoid constituents. Let us be equally consistent.

The position of inclusions in the metal, as we have seen, is governed by the mechanism of solidification of the metal, i.e., by the process of primary or dendritic crystallization. The same or a related mechanism must be responsible, then, for conditions which cause the ferrite, resp. cementite, to appear in association with the inclusions. It is the mechanism of dendritic segregation. This process concentrates the alloy-forming impurities in iron into the dendritic fillings and inter-dendritic spaces, i.e., into places where many (or even most) inclusions also are deposited.

In particular, it is phosphorus which segregates, as has been proved by Stead (25). This phosphorus, as has been shown further by Stead, diffuses only with great diffuculty, even at elevated temperatures, and exerts, at the same time, a repelling action on carbon (or on the carbide Fe_3C) which diffuses readily. As a result the carbon is expelled from regions rich in phosphorus, i.e., from the fillings, which are thereby decarbonized or ferritized. Hence

the ferrite surrounding the inclusions and the presence of inclusions in the ghost lines of forged steel (76). But what about the preferential association of inclusions with cementite?

The author ventures to suggest that such a preferential association does not exist. We took it for granted, heretofore, that inclusions are found primarily in the ferrite, resp. cementite of steel. The basis for this belief is furnished by observations which, in the case of ferrite, are entirely convincing. Not so in the case of the cementite of hypereutectoid steels. Such steels have been studied far less universally than ferrite-bearing steels and the evidence in regard to the occurrence of inclusions in the pro-eutectoid cementite is inconclusive.

We must bear in mind that, while inclusions can be seen quite readily in the structureless brillant surface of unetched iron or steel, their presence becomes far less apparent when an etched specimen is examined. Compare, for example, the readiness with which the presence of individual inclusions is called to our attention in Fig. 63 and Fig. 136 which depict entirely comparable inclusion-bearing areas in pure iron before and after etching. How much more obscuring must be the etching effects exhibited by pearlite! Or of any other constituent in which a fine structure is developed. It is only natural that we overlook the inclusions occurring in pearlite, while we cannot help noticing them in the brilliant structureless cementite.

It appears that inclusions may be associated preferentially with pro-eutectoid cementite only to the extent to which the boundaries of austenite grains are coincident with the boundaries of the primary dendritic crystals, or to the extent to which the development of the austenite grain boundaries has been influenced by pre-existing inclusions. On the whole the existence of a marked preferential association of inclusions with cementite is open to doubt.

In conclusion, it appears desirable to point out that the mechanism of dendritic segregation, although the main cause for the occurrence of inclusions in ferrite areas, may not be the only cause. It is entirely feasible that inclusions, under suitable conditions, may act as nuclei in the process of secondary crystallization of steel (as was suggested by Ziegler), and assist, in this manner, in the accomplishment of a preferential association.

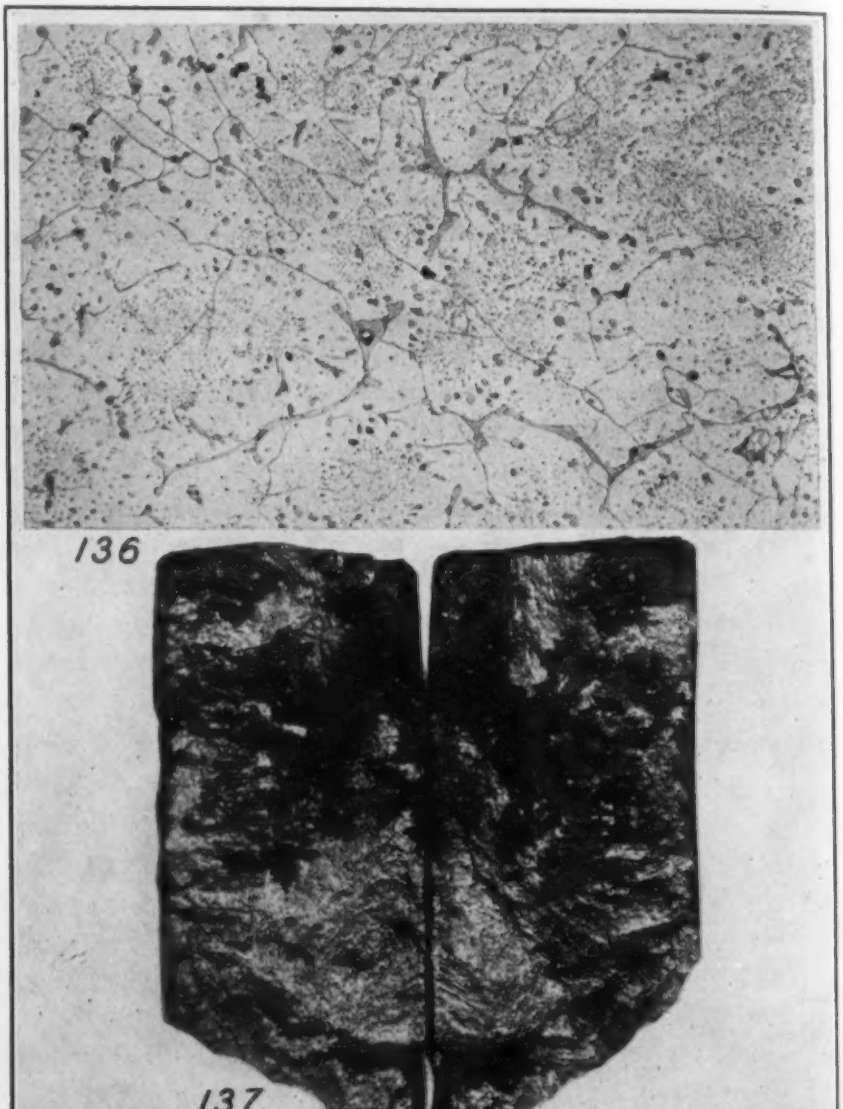

Fig. 136—S-6. Etched with 3 Per Cent Alcoholic Nitric Acid. Grain Boundary Lines are Independent of the Sulphide Inclusions. × 100. Fig. 137—White Cast Iron Exhibiting "Hot Cracks" Broken with a Blow of the Hammer. The Metal Fails Along the Brittle Inter-Dendritic Surfaces of Cementite. × 2.

7. *Identification of Inclusions*

It is not the purpose of this chapter to enumerate the methods which have been proposed and used for the identification of inclusions, nor to present a new method. Attention will be devoted, primarily, to some fundamental considerations which ap-

pear to have received much less attention than they deserve.

It is important, in the first place, to emphasize that the majority of inclusions are not simple compounds as would appear from the "Methods for Identification" proposed. On the contrary, most inclusions are complex solid solutions or aggregates of such solutions.

Secondly, it is important to note that the methods generally used for the identification of inclusions are not precision methods as one might be led to infer from the way in which directions for their application are given.

Etching Tests. Indeed, all of these methods depend on the application to inclusion-bearing steel of certain etching reagents and a visual judgment of the effect of this reagent. The changes produced by a certain reagent in a given inclusion are not only a function of the chemical composition of the inclusion but a function of the size of the inclusion, the duration of the treatment, of the temperature at which it is carried out, and to an important degree, a function of the chemical character of the surrounding material.

Consider, for example, the effect of the 10 per cent solution of chromic acid in water on manganese-bearing sulphide inclusions. In detail, its effects, as described in Chapter III, were found to be highly variable. Indeed, while it attacked successfully the small globules of manganese-rich sulphide it failed to induce noticeable changes in the larger sulphide inclusions of essentially the same composition. Applied to the specimen S-6 relatively poor in MnS, it exerted a profound attack on inclusions but slighly richer in MnS than the limiting solution of FeS in MnS. In the presence, however, of the other inclusions still richer in MnS—as in S-7—it failed even to tarnish inclusions of the very same composition as it blackened and dissolved in S-6.

Chromic acid is a delicate reagent, highly susceptible to extraneous influences. Other reagents, less delicate and less susceptible, such as sulphuric acid, for example, can almost always be depended upon to produce decisive etching effects. These reagents are, however, so powerful as to be incapable of making fine distinctions. The effect of still other etching reagents will, in general, lie somewhere between these two extremes.

We cannot, then, rely on etching treatments as a precise means

for identifying inclusions. The results of such treatments are merely indicative of the constitution of inclusions and must be interpreted in the light of such other evidence as can be secured.

Other Tests. The problem of identifying inclusions is in many ways comparable to the problem of identifying opaque minerals under the microscope. In this latter case we deal, ordinarily, with much larger masses than are provided by inclusions,—masses which often can be studied in detail already at × 100. Yet the mineragraphist finds it necessary to supplement etching tests by precise measurements of hardness (77), color composition (78), electrical conductivity, etc.

How can we then hope to obtain reliable results by etching tests alone, while dealing with particles so minute that a magnification of some 1000 is required to study them comfortably? The very minuteness of these inclusions may prevent, of course, the successful application of some of the tests available to the mineragraphist;—at least until special microapparatus is devised for such tests. Other tests, such as a quantitative color test, are quite feasible, however. Chemical methods of testing could also be improved upon materially; using, perhaps, the micro-manipulator of Zeiss, or other devices of the same character.

For general informative purposes we need not go that far, however. The inclusion problem is very much simpler than the corresponding problem of opaque minerals, in one important respect. While the mineragraphist has to differentiate between hundreds of different minerals, the metallographist has to deal with but a few varieties of inclusions. If observations made in one series of tests are checked by those of another series the results, usually, can be taken to represent the facts.

Check Afforded by the Chemical Analysis of the Metal. It is desirable, in all instances, to check one's findings by referring to the data of a careful chemical analysis of the metal. In the essential absence of sulphur and manganese, for example, it would be entirely out of place to "identify" a number of inclusions as manganese sulphide. On the other hand, if sulphur is present sulphide inclusions must be present. Their constitution will depend, roughly, on the relative amounts of sulphur and of manganese, and of other sulphide-forming metals present. If oxides are present they may safely be assumed to consist of a complex of the oxides

of all the metals revealed by the analysis; in particular, it may be concluded that manganese and aluminum will be united with oxygen in preference to sulphur. The presence of silicon generally implies the presence of silicates. An "insoluble residue" suggests silicates and alumina. The relative amounts of inclusions can also be estimated from the data of analyses, especially if these data include oxygen determinations.

In general, an intelligent estimate on the basis of data of careful chemical analyses, coupled with an examination, preferably at high powers, of a few representative inclusions, will serve to convey a fairly good idea about the nature of the inclusions present.[37] The conclusions arrived at will, surely, be more nearly correct than a conclusion based on the results of "standard" identification methods alone.

Thus, following the prescriptions of Campbell and Comstock's method, the author "identified" some 40 per cent of the inclusions in ingot iron to be "lime wash", some 5 per cent manganese oxide or iron carbide, and the balance—manganese silicate.[38] This result proved to be 100 per cent wrong. And, at least partly, this was the fault of the method which should be more specific in some of its prescriptions and less definite in many of its conclusions.

Campbell and Comstock's Method and its Modification by the Author

Campbell and Comstock's method merits, nevertheless, especial attention. It is more systematic, straightforward and simple than any other method proposed. No cumbersome gaseous reagents are employed, nor heating of the specimen to temperatures which would involve undesirable tarnishing of the polished surface. To the contrary, the specimen is etched in the same manner as for ordinary metallographic purposes, and, in most instances, even in the same reagents.

In his work on inclusions, described in Chapters II-IV, the author has repeatedly employed etching tests prescribed by Campbell and Comstock, and has had occasion to observe their effect on

[37] Attention must be called to the fact that experience with inclusions is an essential prerequisite for judging them, especially by appearance and association.

[38] The inclusions in ingot iron properly identified (see Chapt. VI of the author's thesis) are:

Iron oxide (slightly contaminated)	95%
FeO-FeS eutectic	4%
Sulphide rich in Mn (?)	1%

known inclusions. The results of these tests have already been described.

On the whole Campbell and Comstock's method is good:—to be serviceable, however, it should be considerably modified. Concentrations of etching reagents should, in all cases, be specified definitely and the use of "strong" or "fairly strong" in this connection avoided. Care should be taken to avoid "identifying" inclusions whose existence in iron, in the pure form, is open to doubt. The results of individual etching treatments should be interpreted, in many instances, with greater caution.

These recommendations as well as other desirable changes have been incorporated in a modified "method", presented in Table III. This modified "method" is far from final and, perhaps, even far from serviceable. It is however, a closer approximation to the truth than the original "method".

8. *The Influence of Inclusions on the Useful Properties of Iron and Steel*

The main practical issue of the problem of inclusions centers about the question: What is the influence of inclusions on the useful properties of the metal? Having had no occasion to secure original experimental evidence on this vital question the author must refrain from discussing it in any detail.

Inclusions and Fatigue Failure. According to most metallurgists inclusions are harmful—harmful in direct proportion to their number, and to the extent to which they are segregated. Failures in steel parts have been repeatedly traced to the presence of inclusions, and the detrimental effects of inclusions on the fatigue resistance of metals has been conclusively demonstrated. (21, 24, 28, 32, 41, 44, 79, 80 and many others).

The reason for this harmful effect of inclusions becomes obvious when principles of the theory of elasticity or the strength of materials are applied to the problem. The edges of inclusions are regions of high stress concentration, and this explains why cracks are found so often to start from inclusions. The formation of a crack, no matter how small, serves to increase the concentration of stress; this in turn facilitates further cracking; this again causes increased stress concentration; and so on, until failure is unavoidable.

The presence of inclusions is especially harmful, therefore, in brittle and hard metals in which cracks are easily started. From what has been said it is further evident that small globular inclusions are least harmful, elongated and continuous shapes, as well as localized aggregates, most dangerous.

Inclusions and "Directional Properties." Not infrequently inclusions are blamed for the "directional properties" of forged steel viz., a weakness in a direction perpendicular to that of rolling or forging. The reason for this effect of inclusions lies again in the highly increased stress concentration which takes effect at the ends of the drawn out inclusions, when the material is pulled in a direction across these inclusions. When pulled lengthwise the stress concentration is insignificant.

A lesson about the influence of inclusions can be learned from the behavior of ingot iron. Charpy bars of rolled ingot iron, when tested in directions parallel and perpendicular to that of rolling, show little, if any, difference in impact strength. Does it not follow that the "directional properties" observed in mild steel (which is ordinarily freer from inclusions than ingot iron) are ascribable primarily to segregation phenomena (leading to a banded structure) rather than the effect of inclusions?

It must be borne in mind, of course, that the oxide inclusions in ingot iron are less plastic at rolling temperatures than sulphide inclusions for example; and, being moreover small, they are elongated much less than the larger and more plastic inclusions in steel. The latter, if sufficiently numerous and sufficiently drawn out, unquestionably do weaken the impact resistance of steel, in the direction of the "grain". The relative importance, then, of inclusions and of dendritic segregation in imparting directional properties will differ considerably for different steels. In general, the dynamic strength of a metal will be affected more seriously by inclusions than the strength under static load.

Inclusions and Corrosion. Inclusions are believed by many to impair the resistance of iron and steel to corrosion. While it cannot be denied that this may be the case, the influence of inclusions in accelerating corrosion is far less serious, in the opinion of the author, than the influence of alloy-forming impurities.

The resistance to corrosion of Armco ingot iron which is essentially free from alloy-forming impurities is a case in point. This

Table III

METHOD FOR IDENTIFICATION OF INCLUSIONS IN IRON AND STEEL

By Campbell and Comstock (Modified by Wohrman)

Polish carefully so as to preserve inclusions and project magnified image on ground glass by arc or equally white light without color screen.
GRAY OR BLACK INCLUSIONS
CREAM COLORED (PALE YELLOWISH), YELLOW, RED OR PURPLE INCLUSIONS
Etch 10 sec. with 10% nitric acid in alcohol
Etch 10 min. with boiling alkaline sodium picrate
Strongly attacked = Lime Compound from mold wash (rare).
Weakly attacked (slightly pitted or darkened) = Compound Oxide: (a) either FeO with FeS in solution (usually accompanied by FeO-FeS eutectic)
(b) or FeO + MnO and other oxides in solution.
Note 1. Octahedral crystals are probably magnetite.
Note 2. Both (a) and (b) will be darkened further by 20 sec. sulphur printing (2% H_2SO_4 in water and destroyed by etching with stannous chloride as indicated below.
If Unattacked Etch 5 min. with 10% chromic acid in water. (Be careful to observe that the polished surface is wetted by the solution.
Attacked Iron Sulphide (pale yellowish)
If Unattacked
Purplish color, rather easily polished smooth, is
Chromium Oxide
Yellow cubes or cubic form is
Zirconium nitride
Pinkish color, strongly angular form rather difficult to polish without pitting is
Titanium cyano nitride
Attacked FeS-MnS, rich in MnS. Note. Reaction not always decisive. Any unattacked FeS-MnS will be blackened by the next treatment.
If Unattacked Note Color: (1) Very faint pale gray. (2) Medium or dark gray and etch 5 min. with boiling alkaline sodium picrate.

iron, as is well known, abounds in inclusions most of which are oxides. And, according to Law (25), oxides are especially prone to accelerate corrosion.

"Oxide of iron differs in one respect from all the other impurities in steel. . . . The difference referred to is the influence

Supplementary Tests
In all instances check your determinations in the light of the evidence of a careful chemical analysis, and, whenever possible, by other methods, such as:
I. Sulphur printing (for 20 seconds, using a 2% aqueous solution of H_2SO_4):
(1) dissolves all FeS-MnS inclusions.
(2) partly dissolves (pits) FeO containing FeS and oxides of other metals in solution.
(3) leaves unchanged: iron sulphide (pale yellow) pure iron oxide (med. gray) silicates (dark gray)
II. Matweieff's Tests.
See A. Sauveur's "Metallography and Heat Treatment of Iron and Steel", pages 512 and 513, 1926.
III. Kohl's Tempering Test for Sulphides.
Same reference as in II, page 513.
Completely blackened (1) FeS-MnS, MnS below 50% (2) FeS-MnS, MnS above 50% or oxide very rich in MnO.
Partly Attacked (a) Oxide rich in MnO (will be destroyed by stannous chloride). (b) Silicate with some MnO (will be destroyed by hydrofluoric acid).
If Unattacked (or partly attacked in previous treatments), etch 10 min. with a saturated solution of stannous chloride in alcohol.
Attacked Iron Oxide or (if previously pitted) compound oxide.
If Unattacked (or previously pitted) Etch 10 min. with a 20% aqueous solution of hydrofluoric acid.
Attacked Silicate (if previously pitted presence of Mn is indicated).
If Unattacked Repolish and note color and form.
If fine particles very dark color, difficult to polish without pitting and not elongated by hot work is Alumina
If color not especially dark, easily polished smooth without pitting.
Fairly large angular fragments showing changeable bright spots as focus is changed is Sand Grains (in steel castings)
Small angular particles bluish in color Probably Titanium oxide (in titanium treated steel)

exerted by the impurities on the corrosion of steel. . . .If specimens for microscopical examination or freshly filed surfaces are kept side by side in an ordinary room, it will be seen that steels containing oxide begin to show signs of rusting long before the others. . . ."

The findings of Austin (81) are diametrically opposite, and in all probability more nearly correct. Referring to an oxygen-iron alloy studied, he states: "The author believes that the resistance to atmospheric corrosion. . . .of the alloy. . . . will have technical applications."

Opinions on the subject are, clearly, divided.

Wrought iron is another example of a metal literally crowded with inclusions, yet it is unusually resistant to corrosion.

On the other hand, it is well known that ferrite contaminated by alloy-forming impurities—manganese for example—is attacked by etching reagents much more readily than pure ferrite.

No general conclusions can be drawn on the basis of these rather special examples,—they are, nevertheless, indicative of the fact that inclusions may not be nearly as harmful in inducing corrosion as is held to be the case.

Inclusions and Red-Shortness. Another important effect, largely ascribed to the harmful influence of inclusions, is red-shortness. Iron sulphide, in particular, is held to be responsible for this defect, although it is ascribed, not infrequently, to oxygen, silica and alumina.

Some metallurgists (85, 86, 87) believe copper to be the source of red-shortness; other workers (83) assert that copper actually helps to correct the red-shortness induced by sulphur. Some are inclined to put the blame largely on oxygen (81, 88, 89) others again advance evidence which tends to show that oxygen is harmless (83, 90).

Even in regard to the detrimental influence of sulphur there has been some divergence of opinion; the majority of metallurgists believe, however, that sulphur, in the absence of manganese, is invariably a cause of red-shortness of iron, even if present in quantities barely exceeding some 0.010 to 0.015 per cent.

We shall in the following devote our attention primarily to this peculiar action of sulphur and examine the mechanism whereby sulphur red-shortness is induced.

Already Le Chatelier (16) pictures the disastrous effect of sulphide inclusions, stating: "It can be readily conceived that. . . networks of sulphide, a substance having very little tenacity and melting at 980 degrees Cent., will decrease considerably the resistance of the iron in the cold, and completely destroy it when hot."

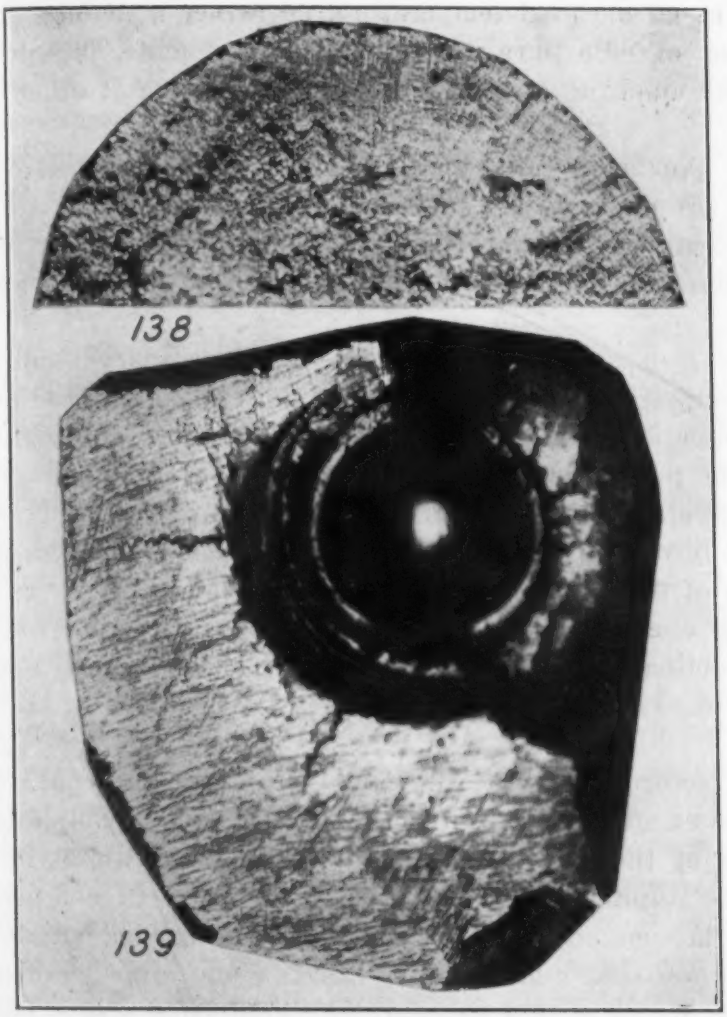

Fig. 138—S-1. (Over 1 Per Cent Sulphur), Broken with a Blow of the Hammer. The Metal Fails Along the Brittle Inter-Dendritic Envelopes of Sulphide. × 3½. Fig. 139—S-1. Failure Under the Brinell Test. × 3½.

Today hot-stortness due to sulphur is fairly universally explained by this tendency of the sulphide to form continuous envelopes around the "grains" of the metal. The envelopes break up the continuity of the metallic mass and cause, when melting at about 1795 degrees Fahr. (980 degrees Cent.), the falling apart of the metal. At still higher temperatures the molten sulphide is absorbed (dissolved) by the iron which then regains its continuity and plasticity. [Ziegler (36)] Let us examine the accepted ideas critically beginning with fundamental considerations.

Hot-shortness or red-shortness implies lack of plasticity, brit-

tleness, at an elevated temperature, or rather a definite temperature interval, of a pure metal, alloy or aggregate, irrespective of the plastic qualities of such a metal or aggregate at other temperatures.

The plasticity (also brittleness) of a substance is (like all physical properties of a substance), in the last analysis, a function of the atomic and of the interatomic and intermolecular bonds of the substance, as well as of the conditions of pressure and temperature.

Pure iron is inherently plastic—at all ordinary temperatures and pressures; pure ferrous sulphide inherently brittle, at any rate at atmospheric pressure and room temperature. Consider an aggregate of pure iron and ferrous sulphide at room temperature. The physical properties of an aggregate can be deduced, roughly, from the physical properties of the constituent substances and the structure of the aggregate. In particular, the plasticity of an aggregate of one plastic and one brittle constituent is determined by the predominance and continuity of the plastic constituent. In the present case the plastic iron is clearly, in excess of the brittle sulphide.

But, according to the testimony of many, the continuity of the iron is effectively broken up by envelopes of the sulphide. Deformation of the iron cannot, then, take place without deformation of the sulphide. The latter, being brittle, will not permit of any deformation and will break under the applied stress. Fig. 138 shows how such a metal (S-1) breaks along inter-dendritic surfaces when struck with a hammer. An analogous case is met with in white cast iron which consists of plastic pearlite dendrites separated by brittle cementite fillings and boundaries. A blow will break the metal the fracture exhibiting a distinct dendritic structure (Fig. 137).

The melt S-1, containing over 1 per cent sulphur was found to be so brittle, on account of the continuity of the sulphide inclusions, (Fig. 43) that it failed when a Brinell reading was attempted (Fig. 139). The melt S-3, with 0.125 per cent sulphur (Fig. 56) permitted such a test, however, and was otherwise, too, essentially plastic in the cold. This is obviously explained by the much less pronounced continuity of the sulphide inclusions in this melt. Now, if even 0.125 per cent sulphur fails to provide continuous mem-

branes, how can we expect 0.02 per cent sulphur to accomplish this or even 0.015 per cent sulphur? No one will deny that Armco ingot iron is plastic at ordinary temperatures; how could it be plastic if continuous brittle sulphide envelopes (which supposedly cause its red-shortness) were present? Or is it the extreme thinness of these envelopes that makes them less obnoxious?—they are absent, as the writer has had occasion to show repeatedly, for the 0.02 per cent sulphur present in ingot iron is accounted for by isolated inclusions. Yet we continue to refer to continuous membranes in explaining red-shortness!

What happens when we heat sulphide-bearing iron? The author heated the partly distintegrated specimen which failed under the Brinell ball (Fig. 139) to 1470 degrees Fahr. (800 degrees Cent.) and forged it without any difficulty to the thinness of a dime. The sulphide, at elevated temperatures, becomes plastic; the iron is plastic; hence the aggregate of the two is and must be plastic. One would expect this plasticity to increase with increasing temperature and this is actually the case. A discontinuity occurs, however, within a narrow temperature interval in the neighborhood of 1740 degrees Fahr. (950 degrees Cent.), the aggregate suddenly becoming brittle. This temperature interval may well correspond to the fusion point of the Fe-FeS eutectic. But should the presence of this material in discontinuous patches affect the ductility of the metal any more than actual voids would?

There is further this peculiarity. No matter how much a red-short metal is worked either above or below the zone of red-shortness, it will fail when subjected to deformation in that zone. On the other hand, cases are known where alloys containing a complete network of a brittle constituent can be successfully worked after the continuity of this network has been destroyed by careful initial working. Jeffries (86, p. 359), for instance, cites an example of cast steel containing 2.65 per cent of carbon which was successfully worked after "gentle" initial working or "breaking down". The extreme thinness of the hypothetical sulphide network should certainly be conducive to such "breaking down." Yet this cannot be accomplished.

Must we not conclude that the cause of red-shortness is of an entirely different nature than the brittleness induced through the presence of a non-forgeable constituent? The constancy of the

temperature interval of hot-shortness for pure iron, the nearness of this interval to the A_3 point, the fact that this interval is lower for steel for which the A_3 point also is lower;—all this points unmistakably to some connection between red-shortness and the gamma-alpha transformation of iron.

It is instructive, in this connection, to recall the phenomenon of "critical plasticity" at the A_3 point, discovered by Professor Sauveur and Dr. Lee (58, p. 108). Professor Sauveur writes: "When a bar of iron or low carbon steel is heated at the center of its length to a temperature exceeding the A_3 point, and then twisted, the twisting does not occur at the center where the bar is hottest, but at two points equidistant from that center where the bar is undergoing its A_3 transformation."

A study of the photographs of the twisted bars (91) suggests to the author that the point of "critical plasticity" does not occur at the A_3 point proper, but in a region of the iron which just completed its transformation and thus represents alpha iron at the highest temperature of its existence. On both sides of this point the plasticity diminishes:—it diminishes toward the alpha iron side on account of the normal fall of plasticity with temperature; it diminishes toward the gamma iron side, in spite of increasing temperature, because of the admixture to alpha iron of gamma iron which is about to be transformed and is thus at its lowest temperature of existence, the temperature of its minimum plasticity. The rigidity of the metal increases steadily with the increase in gamma iron content until finally a maximum of rigidity is reached when we have one hundred per cent of gamma iron at the temperature of its minimum plasticity. From then on the temperature gradient makes itself felt again and the plasticity of gamma iron gradually increases.

These deductions are supported by recent quantitative measurements of the malleability of iron and steel at high temperatures by Ellis (92). Ellis found that "the allotropic change at A_3 occasioned a distinct increase in the resistance of the metal to plastic transformation," and that when "the temperature of inflexion is reached . . . the austenite suddenly hardens." At about 2550 degrees Fahr. (1400 degrees Cent.), presumably the beginning of the delta change, another break in malleability was observed, the iron acquiring here quite suddenly a highly increased plasticity. Ellis is unquestionably correct in concluding that "a change, the

converse of that which occurs in austenite as it approaches the upper critical point (A_3) on cooling, occurs as it approaches A_4 on heating." His interpretation of the cause of these changes,—a "carbide expansion" at A_3 and "carbide contraction" at A_4, is less convincing, however.

It is obvious that the changes are attributable, primarily, to the allotropic changes. Gamma iron, on account of its atomic constitution, is less plastic than alpha (or delta) iron, and is in fact "hard" at the lower temperatures of its existence. What is the bearing of these facts on the problem of red-shortness? The author ventures to suggest the following explanation.

The influence—both beneficial and detrimental—of small amounts of alloyed substances on the physical properties of a metal is well known. Gamma iron lacks plasticity in the neighborhood of 1740 degrees Fahr. (950 degrees Cent.). A small amount of alloyed sulphide (and perhaps oxide) emphasizes this lack of plasticity to such an extent that the iron actually disintegrates when worked. At higher temperatures the plasticity of the alloy is increased sufficiently to allow working. At lower temperatures we deal with alpha iron, inherently more plastic.

The beneficial effect of manganese on the red-shortness caused by sulphur (resp. oxygen) can be explained by the lack of solubility of the sulphide (resp. oxide) in gamma iron in the presence of manganese. It may also be that manganese actually helps to improve the plasticity of gamma iron.

The entire problem of red-shortness is thus reduced to the problem of gamma iron or austenite plasticity in the lower temperature regions of its existence, and to the effect on this plasticity of various alloyed elements, and the amount of such alloyed elements.

It may be recalled, in this conection, that certain nickel steels, for example, have a tendency to be red-short (82). This may be accounted for by the influence on the plasticity of austenite of the particular amount of nickel present. And, again, it is manganese which has been found to render these steels forgeable (93).

Inclusions, then, have little influence on the malleability of iron and steel at elevated temperatures. At least not the inclusions which are plastic at hot-working temperatures. Inclusions which are substantially hard at these temperatures, and at the same time

sharp-edged, such as alumina and silica, may, however, be expected to exert some sort of "tearing" action on the weakly plastic metal, thus causing it to break on severe deformation.

Beneficial Influences of Inclusions. We have mentioned, heretofore, only the harmful and undesirable influence exerted by inclusions on the metal that harbors them.[39] There is little to be said in their favor.

One may mention, perhaps, that the presence of sulphide in mild steel improves its "free cutting" properties and that the "fiber" created by elongated FeS-MnS inclusions in severely worked steel shapes is supposed to contribute toward the strength of such shapes in a longitudinal direction. It has also been claimed that the presence of oxide inclusions accounts for the unusually favorable enameling qualities of Armco ingot iron.

Conclusions. On the whole, inclusions are harmful and undesirable. The harder the inclusion-bearing metal, the greater the number of inclusions present, the larger their size, the more complete their continuity and segregation, the more dangerous they are. Inclusions, in all instances, lower the fatigue resistance of a metal. Their effect on the "directional properties" of worked material is probably less marked than is generally assumed.

Inclusions play but a secondary role in the importance of their contributions toward the corrodibility of metals, as well as the phenomenon of red-shortness in metals. Alloy-forming impurities should be held responsible for these defects.

9. *The Elimination of Inclusions*

Having considered the inception and birth of inclusions, looked into their behavior and habits, and studied their characteristics and harmful influences, the logical and desirable thing to do would be to write a chapter on their death. This chapter, unfortunately, cannot be written as yet. And it will hardly be written as long as present methods of steel-making continue in use in their existing form.

We make steel by a process which depends on oxidation. Iron oxide dissolved in the molten product will, therefore, invariably

[39] The harmful influences which were mentioned are not the only ones. Of those omitted, the well known effect of inclusions on case hardening is, perhaps, the most important. Inclusions, notably oxide inclusions, are the cause of the so-called "soft spots" which are highly undesirable in a good case.

be present. Deoxidizers may eliminate most of the iron oxide, but they substitute another oxide (viz., silicates, aluminates) for it, which, ordinarily, is not eliminated before solidification. Worse still, an excess of the deoxidizer may, in some cases, be more harmful to the metal than the inclusions it was meant to correct. The best we can do, at the present, is to limit the nuisance of inclusions by wisely directing our furnace and ladle operations and by choosing a harmless deoxidizer which, at the same time, is least liable to contaminate the steel with its oxidation products, i.e., a deoxidizer whose oxidation products have a strong tendency to escape from the metal and whose products, if entangled in the metal, will occur in relatively harmless form—the form of tiny globules evenly distributed.

Having performed no experiments in this direction, the author avoids, on purpose, to be more specific in his recommendations.

It is clear that inclusions once formed are with the metal to stay and that nothing short of remelting will exterminate them. Inclusions cannot be remedied; they must be prevented.

Cleanliness of materials and care of operations will go a long way toward accomplishing this. Electric steel is a point in case.

Scientifically controlled cooling and solidification conditions, as yet largely unspecified, will afford further relief. A prolonged period of fluidity after the last additions are made will unquestionably help the suspended matter to leave the metal. If this be followed by slow solidification in vacuo, gases would also be eliminated. To correct segregation which would be favored by quiet slow cooling, solidification should not be allowed to take place undisturbedly. The metal should be worked by some means, already while still essentially fluid.

There are other possibilities. Many of them are impracticable today, many of them imply refinements as yet uncalled for. They may be called for tomorrow and we should be ready for them.

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Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XXI[1]

By H. B. Knowlton

Abstract

This article discusses various special types of heat treating furnaces, including continuous furnaces, liquid baths, furnaces depending upon the critical point, special tempering furnaces, etc.

The various schemes of quenching, the regulation of the temperature of the quenching bath, and the conveying and handling systems are also discussed. Finally some suggestions are made concerning the layout of the heat treating department and the personnel necessary for successful operation.

Special Types of Heat Treating Furnaces

IN the last chapter, the simplest type of heat treating furnace, the box or oven-type, was discussed in some detail, in order to bring out some of the fundamental principles which govern all heat treating furnaces. What was said with regard to pyrometers, oil, gas and electric heating, and the general principles of operation of the simple box-type furnaces will apply in the main to the more complicated types of furnaces. It remains for us to discuss some of the special types of furnaces.

Obviously it will be impossible to describe every type of furnace, therefore it will be attempted to describe only typical

[1]This is the twenty-first installment of this series of articles by H. B. Knowlton. The several installments which have already appeared in Transactions are as follows: March, June and October, 1925; January, April, May, June, August, October, December, 1926; March, May, July, September November 1927; January, May, July, August, September, 1928.

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examples. It should also be stated at the outset that no particular make of furnaces is being favored. Most of the types mentioned are manufactured by a number of furnace companies. In general it may be said that the trend of modern design is to make the furnace as simple and as automatic as possible so as to eliminate the human factors from the equation as far as possible. Also they should be as economical as possible, and whenever practicable they should be continuous. Like the box-types, the special furnaces must of course heat at the desired rate and maintain the stock at the desired temperature for the required length of time.

Car-Type Furnaces

The simplest form of car-type furnace is merely a large box-type furnace in which the hearth and bottom of the furnace is the floor of a flat car which runs on a miniature railway in and out of the furnace. Such a furnace is commonly used for annealing of steel castings and other large parts. Steel castings are frequently piled several layers high on such a car and are run into the furnace, and the whole charge brought up to the annealing temperature. After being kept at the annealing temperature for several hours the car may be pulled directly out into the air, or the charge may be allowed to cool down with the furnace. The former case is usually called air cooling, although there may be considerable difference in the rate of cooling of the castings on the top from those in the center of the pile on the car. Some steel foundries have reported that in the case of certain steel castings this difference in the rate of cooling makes much less difference than it does when the castings are made of plain carbon steel.

In appearance this is a simple type of furnace but it is really a difficult one to heat uniformly, due to the large size of the furnace and the mass of castings to be heated through. It is a real problem in furnace engineering to heat such a furnace properly.

Somewhat smaller car-type furnaces are used for heat treating large die blocks and other large sections. When such parts are to be quenched there should not be many pieces on the car at the time. Die blocks are lifted off with hoists as soon as the car is removed from the furnace and are placed in the quench-

ing bath. They may be "time-quenched" in this manner for the desired time and then be placed on another car and run into the tempering furnace while the center of the block is still fairly hot.

Car bottoms may also be used in continuous furnaces. In this case the furnace is much longer and contains several cars on the same track. Periodically a car loaded with cold work is pushed into one end of the furnace. This advances the position of all of the cars by one car length and pushes the last car out the discharge door. Such a furnace falls in the class of continuous furnaces about to be discussed.

Continuous Furnaces

There are a number of different types of continuous furnaces on the market. Wherever there is a sufficient production of parts of the same size which are to receieve the same heat treatment, the continuous furnace has some decided advantages. In such a furnace cold work is started in one door of the furnace and is advanced, more or less automatically through the furnace to the discharge door. This is a good production tool, as there is a continuous flow of work through the furnace. If the furnace is designed properly the work can be brought to the final temperature at any desired rate of heating without slowing up production. The problem of heating all pieces uniformly to the same temperature is somewhat simpler in continuous furnaces because all pieces pass along the same path through the furnace. These furnaces are usually economical from a fuel or heat standpoint because the hot gases from the hottest zone of the furnace to some extent help heat up the work near the charge door. (This of course will depend largely upon the design of the furnace.) Continuous furnaces are frequently divided into two or more heating zones. The amount of heat units (in the form of fuel or electricity) delivered into each zone is controlled by a thermocouple in that zone. Thus it is possible to deliver a large number of heat units continuously into the first, or "bringing up," zone of the furnace without overheating the high heat or holding zone of the furnace. If the heat input of the whole furnace were controlled by a thermocouple in the hottest zone there would be no heat delivered into the "bringing up" zone as long as the hot zone was at the correct temperature.

Straight Through or Tunnel Furnaces

There are a number of types of continuous furnaces, one of the simplest of which is the "straight through" or "tunnel" furnace. This is usually a long and comparatively narrow furnace. The work to be heated is charged through a door at one end of the furnace and is advanced gradually through the furnace. If the furnace is small it may contain a single heating zone. Longer furnaces usually have two or more heating zones each controlled independently by a thermocouple and pyrometer controller. As the work advances through the furnace it is gradually brought to temperature and finally is held at the desired temperature for the required length of time. If the steel is to be quenched from this furnace it is usually considered best to remove it from the hottest part of the furnace and quench it as rapidly as possible. Sometimes the extreme end of the furnace is not the hottest part and the work is either carried rapidly through this portion or else is discharged through the side or bottom of the furnace before reaching the extreme end. It might be remarked in passing that a slight drop in temperature before quenching is not as serious from a metallurgical standpoint as is sometimes thought. As long as the temperature remains above the Ar_3 point the steel will harden.

In annealing furnaces there must be a cooling zone beyond the hot zone. The rate of cooling in this zone depends upon the construction of the furnace and the rate of travel of the work. Sometimes dampers are placed in the furnace so as to help control the speed of cooling. One method of cooling for annealing consists in dropping the temperature rapidly from the high heat to just above the Ar point of the steel and then cooling very slowly through the critical point. Sometimes burners are placed in the cooling zone to retard the cooling while passing through certain temperatures. The final discharge temperature depends upon the length of the cooling zone, the speed of cooling and the rate of travel of the work.

The method of conveying the material through the furnace depends upon the kind of material handled. The car bottom-type for large parts has already been mentioned. Among the other types may be mentioned the belt conveyor, the roller hearth, the walking beam and the pusher types. The belt conveyor is

used largely for small parts of miscellaneous shapes. The principal difficulty to be overcome in this type is failure of the belt to stand up under the heat. The walking beam periodically lifts the work up, advances it, and sets it down further in the furnace.

There are several varieties of pusher-type furnaces. Piston pins and similar parts may be laid end to end in parallel grooves in the hearth. A pusher at the charge end of the furnace pushes in one row of pins and advances all of the pins in the furnace, at the same time discharging the pins at the far end. This calls for a grooved hearth which will withstand heat and some abrasion without warping, scaling, or wearing badly. Some furnaces have two or more alloy heat resisting rails running the long way through the furnace. The work is pushed along these rails. This makes an excellent furnace for parts which can be pushed in this manner. As the work is supported on or above the rails it does not come into contact with the hearth. There is good opportunity for circulation of the hot furnace atmosphere all around the work. In this type of furnace the work is layed crossways on the rails. Some shafts, connecting rods, axles, etc., are of such a design that they can be pushed directly on the rails. This may require "nesting" the parts together. For example, in loading connecting rods it may be necessary to have the large end of every other rod pointing the same direction. In the case of parts which cannot be pushed together, it may be practicable to use special rails and riders or carriages to convey the work through the furnace. In this case the riders are longer than the widest part of the piece to be carried and the riders are pushed one against the other. Boxes and pans may be pushed on solid rails or on roller rails.

The roller hearth furnace has alloy rollers in the furnace which advance the work. This is applicable to certain classes

Counterflow Furnaces

The counterflow furnace is a variation of the straight through type. It is used for such operations as carburizing and annealing where slow cooling in the furnace is desirable or at least not objectionable. One type of counterflow furnace has a hot zone in the center of the furnace and a heat interchange zone at each end of the furnace. The counterflow furnace must contain at

least two rows of work and may contain more. Alternate rows are pushed in opposite directions. Thus there is hot work coming out and cold work going in each end of the furnace. The hot work coming out gives up a great deal of its heat to the cold work entering the heat interchange zone. From a heating standpoint this furnace is very economical, providing of course it is kept full of work. Like many of the other continuous furnaces this furnace is not practicable unless there is sufficient production to keep it busy.

Several variations from the above described design are in use. In one of these the work advances on a row to the end of the furnace and is then transferred to another row and returned through the furnace and out the same door through which it entered. Such a furnace must be shorter and wider than the one first described if it is to handle the same production. In still another type of furnace one row is above the other.

Preheaters and Recuperators

While discussing the utilization of waste heat some mention should be made of the use of recuperators for fuel-fired furnaces. These make use of the heat in the flue gases for preheating the air. Both electric and gas heated preheaters are also sometimes used in preheating fuel oil for oil burning furnaces. Recuperators and other preheaters may be used in connection with various types of fuel-fired furnaces.

Rotary Hearth Furnaces

Another type of continuous furnace contains a flat circular hearth which rotates around a stationary core. The width of the hearth may vary from 2 to 4 or 5 feet. This type of furnace is used for hardening, tempering, and carburizing. The furnace used for carburizing is necessarily larger than those used for hardening and tempering. The work is entered through the charging door and laid on the hearth. As the hearth rotates the work gradually becomes hotter. The discharge door is usually very near the charging door. Consequently the work makes nearly the complete circle before reaching the discharge door. Sometimes a single operator can handle both charge and discharge. In other types of furnace the hearth plates dump auto-

matically at the discharge point. These furnaces may be heated by oil, gas, or electricity. They are frequently divided into heating zones separately controlled by pyrometer controllers. The rate of heating, the final temperature, the soaking time and the production per hour depends upon the design of the furnace, the manner of heat application, the position of the thermocouples, the setting of the controllers, the speed of rotation of the hearth and the weight of the charge. This type of furnace is used for work which is to be removed from the furnace without any cooling from the highest temperature. Thus it is applicable to hardening, and tempering operations, and carburizing which is to be followed by direct quenching from the carburizing temperature.

Vertical Furnaces

There is at least one type of vertical continuous heating furnace on the market. This is used particularly for heating ring gears for hardening. The gears enter the furnace through the bottom and gradually are raised to the top. They are removed for quenching from the upper part of the furnace.

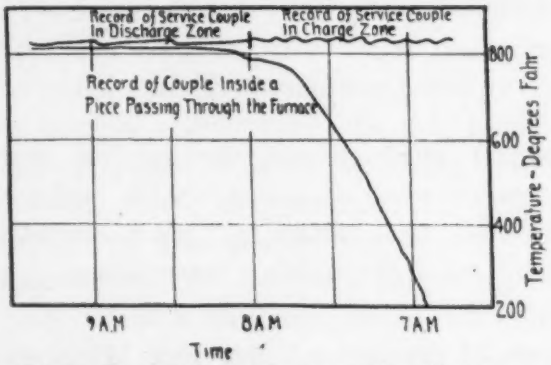
Continuous Heating Barrel Furnaces

A horizontal rotating barrel or drum with a screw or helix inside to advance the work is suitable for heating some parts. This has been used for ball bearing balls, for example. The balls are fed in through a hopper at one end and discharged through a chute leading from the hottest zone of the furnace (which may be a little way from the other end of the furnace).

Selection, Installation and Operation of Continuous Furnaces

As has been stated before, it is the trend of modern design to make the continuous furnaces as automatic as possible and eliminate the personal errors of operation. It should not be assumed that all the heat treater has to do is purchase one of these modern heat treating machines and all his troubles will be over. Human brains cannot be eliminated from heat treating. As is the case with all other automatic machinery, considerable brains must be employed in the selection, design, installation and regulation of continuous furnaces.

In the first place the work to be heat treated must be studied and the furnaces selected which are the most suitable. This will depend partly upon the quantity of production. The designer of the furnace must be informed concerning the kind of work to be handled, the rate of heating, the final temperature, the soaking time and the production per hour desired. In the case



Curves Showing Test of a Tempering Heat in a Continuous Furnace.

of furnaces in which the work is to cool before discharging, the designer must also know the rate of cooling and the final temperature desired.

After the furnace is installed it is the responsibility of the manufacturer or the user of the furnace to work out the setting of the controllers, the load, and the rate of travel and other conditions which will produce the best conditions. Changing the position of the thermocouples often helps materially. Sometimes it is found advisable to cover some of the flues in order to throw more heat to some particular part of the furnace. The rate of input of heat is also important. In the case of gas-fired furnaces there is usually a high and a low to be adjusted. Once all of these conditions have been worked out and have been proved to be correct, it should be possible for the furnace to "take care of itself" without the help of a highly skilled operator. Controllers, burners, switches, and mechanical and electrical parts will of course need the occasional care of a good maintenance man.

In studying a new furnace and making the necessary adjustments, nothing is of greater value than running a test couple through the furnace with the work. Preferably the end of the couple should be in the center of a piece of steel of the same

approximate size and shape as the work customarily handled in the furnace. It is entirely possible to convey work through a continuous furnace so fast that it will not reach the temperature shown by the service thermocouples in the furnace.

The accompanying illustration shows the charts of a thermocouple passing through continuous furnaces. The chart selected shows correct adjustment of the furnace.

Gas Carburizing Furnaces

The horizontal rotating and the vertical stationary retort carburizing furnaces were discussed under carburizing. It was also mentioned that the horizontal retort furnaces were used satisfactorily with solid carburizing materials.

Heating Methods Depending Upon the Measurement of the Critical Point

The furnaces thus far described are regulated so as to maintain some predetermined temperature. There are, however, some heating methods which depend upon the determining of the critical point of every piece of every batch of steel heated.

One of these employs a vertical barrel-type furnace. The vertical cylindrical heating chamber in the center is surrounded by electrical heating elements and the refractory and insulating lining. A removable cover is provided which prevents heat losses through the top of the furnace. The thermocouple projects upwards through the center of the bottom.

This type of furnace has been used a great deal in heating dies for hardening. The die to be heated is placed directly above the thermocouple. If there is a hole in the tang of the die the thermocouple may be inserted in the hole. In either case the thermocouple measures the temperature of the die rather than the temperature of the furnace. The thermocouple is connected with a recording meter, so that a continuous record is made of the heating of the die. When the die reaches the critical point the temperature remains constant for a few moments and then continues to increase. This produces a bend or "hump" in the curve drawn by the pyrometer recorder. By experience it has been found best to allow the temperature of the die to

rise a certain number of degrees above this critical point before removing and quenching. The exact number of degrees above the critical point which should be used for the quenching temperature will depend upon the character of the die or tool and the purpose for which it is to be used. For example, fine edge tools which require extreme hardness but little penetration of hardness should be quenched very close to the critical point, while cold heading dies should be heated a great deal higher.

It is claimed that the distance above the critical point is a much better criterion for quenching temperature than the actual temperature in degrees above zero. As this method actually determines the critical point of each die heated it eliminates errors due to variation of critical temperatures of different steels. It is further claimed that this method not only produces more uniform physical conditions in the parts hardened, but that it also goes a long way toward the elimination of distortion because it is claimed that the minimum amount of distortion in quenching is produced by quenching from a certain number of degrees above the critical point.

It has been mentioned previously that distortion is due in part to too rapid heating particularly in the case of large pieces. The heating method just described has recently been improved by the installation of a second thermocouple in the heating chamber between the die (or other work) and the heating elements. Whenever the difference in temperature between the heating chamber and the die, as shown by the two thermocouples, exceeds a certain number of degrees (50 degrees Fahr., for example) the current going into the heating elements is immediately shut off. As soon as the temperature of the die approaches to within that number of degrees to the temperature of the oven the current is again turned on. This method eliminates personal errors from the control of the speed of heating and assures that the surface of the die will never be more than the desired number of degrees hotter than the center.

For simplicity, this method has been described as applied to the heating of a single die at a time. The same method has been successfully applied to the heating of a large variety of tools (other than high speed and other high alloy tools) and to the heating of automotive gears. When gears or small tools

are heated, it is necessary to place a number of pieces in the furnace at the same time. The pyrometer then records the critical point of the batch. Obviously it is advisable for all pieces in a single batch to be made from the same heat of steel.

Before leaving this method it should be mentioned that it eliminates errors due to the inaccuracy of the pyrometer. No matter whether the thermocouple and the meter is calibrated correctly or not they will show the time when the steel passes through the critical point as a bend in the curve on the pyrometer record. It is sufficient to quench from the desired number of degrees above this point without being concerned as to what the actual temperature of the critical point is.

Determining the Critical Point by Expansion

Another method of controlling heating involves the determination of the critical point by measuring the expansion of the steel being heated. The expansion of the steel is proportional to the increase of temperature up to the critical point. At the critical point the expansion stops momentarily, in fact the steel may even contract slightly. After the critical point is passed the expansion continues.

This change in the expansion of the steel has been made use of in commercial heat treating. In one method a rod of quartz (or some other material having practically no expansion with increase of temperature) is rested on top of the steel being heated. The upper end of the rod is connected with an indicator. As the steel expands the rod is pushed upward and the indicator shows the amount of the expansion. If a recording indicator is used it will draw a curve of expansion which will look much like the pyrometer record and will show the critical point in the same way as a bend in the curve. This is a purely mechanical means of determining when the steel reaches the critical point. For it there is claimed the advantage that it eliminates the pyrometer altogether.

The same principle has been used to some extent in the heat treatment of large shafts and other similar parts. The shaft is heated by passing an electric current through it. One end is held stationary while the other is free to move with the expansion of the shaft. The temperature can be determined by the

expansion and the critical point can be determined by the momentary stopping of expansion.

General Remarks on Methods Involving Determination of the Critical Point

These methods of heat treating which involve the determination of the critical point give some very good results on certain classes of work. They are not applicable to high speed steels nor to some of the other high alloy steels, as these steels must be heated quite high above the critical point in order to bring about complete solution of the alloy carbides. Neither are they applicable to low carbon steels. Such steels have two or more critical points depending upon the carbon content. Sometimes the upper critical point is hard to determine and yet this is the point that must be considered in heat treating. The methods have been used commercially in the heat treating of dies, tools, gears and some other parts. For some other classes of production work continuous and other types of special furnaces are still more popular.

It should be mentioned that some of these methods are covered by patents. For further information consult the makers of the special equipment.

Liquid Bath Heating

Heating for hardening by immersion of the steel in liquid baths has been popular for some years. The liquids used for the ordinary hardening temperatures are usually melted lead or some salt or combination of salts in a melted condition. Among the salts used for high temperatures may be mentioned, barium chloride, sodium chloride, potassium chloride, potassium cyanide, sodium cyanide, sodium carbonate, etc. Usually a mixture of two or more salts is employed as the melting point of the mixture is lower than either of the salts alone. There are a number of specially prepared mixtures on the market which are recommended for different ranges of temperature. It will not be attempted in this article to discuss the relative merits of different mixtures. The mixture selected should have a melting point somewhat lower than the temperature at which it is to be used. Preferably it should not give off much gas or change

greatly in composition when heated. It should not have a corrosive action on the steel nor on the containers and should not carburize or decarburize the steel. In general it may be stated that salt mixtures containing cyanide add a case to the steel which may give a deceptive hardness value. Some salts have an injurious effect.

The melted lead and melted salt mixtures are contained in metal pots which are supported more or less permanently in specially designed furnaces. These furnaces may be heated by oil, gas or electricity. The design of these furnaces will not be discussed except to say that the burners of fuel-fired furnaces should be placed so that no flame impinges directly upon the pots. Direct action of the flame on the pot will weaken the spot attacked and eventually cause a hole. Pots of cast iron, pressed steel, cast steel and cast and pressed alloy have been used. Alloy pots are more expensive but have a longer life.

All types of liquid bath furnaces can be arranged for automatic control, no matter whether the heating be oil, gas, or electricity. It frequently happens that the charge of cold work placed in the bath is large enough to cause the temperature of the bath to drop 100 degrees or more. If a rapid rate of heating is used the temperature will continue to increase (or "drift") after the controller shuts off the input of heat. This may be overcome by slowing down the rate of heating or by decreasing the amount of work placed in the bath at one time. Either procedure obviously means a decrease of production. An increase in the size of the bath will mean less drop in temperature when the cold work is inserted. In this case a slower rate of input of heat can be used and still maintain the same total time of heating and cut down the amount of drift. When the drift cannot be eliminated the controller should be set to shut off before the desired temperature is reached. If the controller is set properly the temperature will drift to the desired point and remain constant for a minute or two.

There are several advantages of heating in a melted bath. As the steel is completely immersed in the bath the air is entirely excluded during heating, and, consequently, scaling is eliminated. When melted salt is used the liquid salt sticks to the work while it is being transferred from the heating bath to the quenching

tank, thus protecting the steel from exposure to the air at that time. The salt cracks off when it comes into contact with the quenching medium.

Another advantage of liquid bath heating is the uniformity of the application of the heat. As the bath completely surrounds the steel the heat is applied from all sides at the same time. On the other hand it is sometimes charged that the rate of heating in a bath is too fast. It is also claimed that it is easier to maintain all parts of a bath at the same temperature than it is to heat an oven furnace uniformly. Similarly it is claimed that there is less likelihood of error in bringing the temperature of the steel to that of the furnace when the liquid bath is employed.

Between the use of melted lead and melted salt there are several points to be considered. Due to the higher specific heat of lead the temperature of a lead pot changes more slowly than that of a salt pot. The drop caused by the insertion of a given weight of work is much less and the rate of heating is greater, other things being equal. On the other hand, lead is more likely to remain sticking to the work after the latter has been quenched. This is particularly offensive in screw threads but can be largely overcome by keeping the lead clean. A layer of charcoal or some other form of granular carbon on top of the melted lead will prevent the air from reaching the lead and forming a thick oxide slag which is very prone to stick to the steel. Sometimes it is practicable to shake or even brush the work after removing from the lead and before quenching. The use of lead for temperatures above 1550 degrees Fahr. is not so desirable on account of the volatilization. Below 700 degrees Fahr. lead is quite thick and likely to stick to the work. The above temperatures cannot be given as exact points, as the properties of lead change gradually with varying temperatures. Various salt mixtures have been used for temperatures ranging all the way from low tempering temperatures of about 400 degrees Fahr. up to the high temperatures used in hardening high speed steel. No one mixture can be used for the entire range. Each mixture has its own range of temperature. As a minor difference between heating in melted lead and melted salt it may be stated that steel must be held down beneath the surface of the melted lead, because the specific gravity of lead is greater than that of steel. On the other hand, steel must be supported in salt pots.

It should be mentioned that some limited use has been made of the rapid heating of the lead pot in producing surface hardness of high carbon steel. In this case the time of immersion must be controlled very accurately so that the surface layers of the steel will reach the hardening temperature while the core will not become hot enough to harden.

Liquid Baths for Tempering

Both lead and salt baths are used for high tempering temperatures. For temperatures below 600 degrees Fahr. either oil or low tempering salts may be used. If the former is selected, an oil having very high flash and fire points should be selected. The usual flash point of tempering oil is about 550 degrees Fahr. This is the temperature at which the gas given off by the hot oil will flash if a small flame is passed above the surface of the oil. It is not usually safe to heat an oil much above its flash point. If baskets are used in connection with oil pots the greatest fire risk occurs when the basket is raised out of the hot oil. The thin film of oil adhering to the sides of the basket is exposed to the air and the ideal conditions for a fire are present. It should be needless to say that when oil tempering pots are used smother covers and fire extinguishers should be handy. When a pot catches fire it is a minute's job to put out the fire with an extinguisher, but it will immediately catch fire again unless the temperature of the oil is reduced below the fire point. This can be easily accomplished by putting in a large number of pieces of cold steel.

The oil tempering furnace is usually somewhat different from the higher temperature pot furnaces in design. In general the oil pots are heated by gas or electricity. When gas is used, it is usually unnecessary to have a blast of air under pressure. An ordinary low pressure gas burner will admit enough air for the low temperatures to be attained. Thermometers instead of thermocouples are frequently used.

Safety and Health Precautions

All bath-type furnaces should be properly hooded so as to carry away fumes and as much heat as possible. It cannot be stated too emphatically that care must be used not to immerse any wet object in a hot bath. The sudden generation of steam

will cause an explosion, endangering the eyes of the operator. It is safe procedure to heat everything to be immersed in a hot bath, to above the boiling point of water. Pieces covered with oil are not so dangerous. The oil vaporizes more gradually and does not cause the violent explosions.

Use of Bath Furnaces for Double Heating Processes

It is a well known fact that the critical point on heating of any steel is considerably higher than the critical point on cooling. Consequently steel must be heated to some temperature above the critical point on heating before it acquires the power to harden, but it does not lose the power to harden until the temperature falls below the critical point on cooling, which may be lower by 100 degrees or more, depending upon the analysis of the steel. This means that the old adage, "Always quench on a rising temperature," is really not necessary. If the steel is heated to the right temperature it may be allowed to cool to any temperature above the Ar point or critical point on cooling before quenching and it will still harden.

Peculiarly little use seems to have been made of this fact. At least one metallurgist, however, has made use of this principle to advantage in commercial work. He was having trouble with distortion of a certain alloy gear when quenching in oil from above the Ac point or critical point on heating. He overcame the difficulty by using two liquid bath furnaces. In the first bath he heated the gear to the usual temperature above the Ac point and then, instead of quenching in oil, he transferred the gear to another lead pot which was maintained at a temperature slightly above the Ar point. After allowing the gear to cool to the temperature of this pot, it was removed and quenched in water. The quenching temperature being considerably lower than the one usually employed the distortion due to quenching was much less. Also since the quenching temperature was above the Ar point the hardness produced was the same as if the gear had been quenched from the higher temperature of the first pot.

For producing treatments of this kind the liquid bath furnace is ideal, as it produces rapid cooling to the desired temperature and assures that the final quenching temperature will be correct.

Bath Quenching and Tempering for High Speed Steels

Tempering high speed steel by heating in melted lead or melted salt at temperatures around 1100 degrees Fahr. is quite common. Some hardeners believe in removing the high speed tools from the high heat furnace and immersing them immediately in the salt or lead bath at the tempering temperature. In this way they seek to combine the quench and the temper into a single operation. The value of this method has been disputed in some quarters, but it is worth mentioning.

Special Tempering Furnaces

The use of lead and salt pots and oil tempering furnaces has already been discussed. Any of the oven furnaces either continuous or batch-type may be used for tempering providing the input of heat can be controlled so as to hold the oven accurately at the desired tempering temperature. It is an easy matter to hold the furnace at the higher tempering temperatures but often difficult to hold them at low tempering temperatures (400 to 800 degrees Fahr.), for example. Some of the electric hardening furnaces and some of the gas-fired furnaces which are provided with special small burners have worked satisfactorily. In addition to these there are certain furnaces which are designed particularly for low temperature work.

One of these furnaces is a vertical barrel-type electric furnace. The work is placed in a basket in the center of the furnace and the top is covered with a lid. A fan in the top and another one in the bottom force air currents alternately up and down through the charge and assure the maintenance of a uniform temperature throughout. Such furnaces work very well for temperatures from 100 up to about 1200 degrees Fahr. The consumption of electricity per pound of steel heated is very low.

There are also special gas-fired furnaces for low temperature tempering. Oil firing does not work so well for low temperature work, due to the high temperature necessary for the combustion of the oil. Whether this difficulty will be overcome only time can tell.

For color tempering, hot plates and sand baths have been used. It seems that the modern tendency is away from the color tempering, due to the inaccuracies of the method.

General Remarks on Furnaces

In the preceding paragraphs it has been attempted to describe typical kinds of furnaces. It is appreciated that it is impossible to describe every kind of furnace. It is hoped merely that the foregoing discussion will give the reader at least a bird's-eye view of the field of heat treating furnaces. Details of design and all expressions of preferences have been carefully eliminated.

Heat Resisting Alloys

It should be mentioned before leaving the subject of furnaces that the heat resisting alloys have played no small part in the development of the modern heat treating furnaces. Rails, rollers, conveyor parts, hearth plates and, in short, all metal parts which are in or pass through the hot zones of modern heat treating furnaces must, necessarily, be made of heat resisting alloys. The composition of these alloys varies greatly. In general, most of them contain nickel or chromium or both. The quantity of alloy present varies from about 10 or 15 per cent up to 90 per cent or more. These alloys are sold both in the form of castings and rolled sheets.

Preventing Scale

One of the big difficulties to be overcome is the preventing of scale in hardening of finished parts. It has already been mentioned that scale can be largely eliminated by heating in salt pots or lead pots. Electric furnaces which are nearly air tight or which, at least, do not allow the passage of a current of air through them, produce a minimum amount of scale. In fuel-fired furnaces the mixture of fuel and air should be so adjusted that the atmosphere in the furnace is nearly neutral or, perhaps, a little reducing in nature. In other words, there should not be a large excess of free air in the furnace.

When these methods fail to eliminate the scale it may be found that immersing the work for several minutes in a weak hydrochloric acid (muriatic acid) solution before placing it in the furnace will help. Calcium chloride, and acid copper sulphate solutions are also said to be helpful.

Quenching Mediums and Equipment

The fundamental principles involved in quenching were dis-

cussed in an earlier chapter. It will be remembered that the object of quenching is to produce the desired speed of cooling. In practical heat treating it is necessary to be able to produce different rates of cooling. The speed of cooling depends upon the nature of the quenching bath, the temperature, the volume, and the speed of circulation.

Many liquids have been used for quenching. In general, they may be divided into three classes: oil, water, and salt or chemical solutions. Other things being equal, the oil produces the slowest cooling and the salt solution the most rapid cooling. Thin oils, generally, produce faster cooling than thick ones because they flow more freely and, consequently, keep fresh in contact with the steel being quenched. It should not usually be necessary to employ more than one kind of oil in any one hardening room. Obviously the oil selected should have a high enough fire point to reduce the fire risk of quenching to the minimum. The use of kerosene is not advisable on account of the fire risk. The same speed of quenching can be attained by other means. It is also obviously desirable that the quenching oil shall change as little as possible on use.

There is even a slight difference between the quenching speeds of different kinds of water. In general, the harder the water, the faster will be the quenching. If common salt or certain chemicals are added to water the quenching speed is increased. On the other hand, the addition of soap decreases the speed of quenching. Solutions containing acids, alkalies and salts have all been used. Many of these solutions are more or less corrosive and injurious to pumps and valves of circulating systems. Among the most popular of the salt solutions may be mentioned common salt or brine, and calcium chloride calcium brine solutions. Of the two the calcium chloride solution produces the faster quenching.

The temperature of the quenching bath also influences the speed of cooling. In the case of water and salt solutions, the colder the bath, the faster will be the quench. On the other hand, some oils, particularly thick ones, produce a faster quenching speed if somewhat warm. This is because the oils are thinner and more fluid when warm. When hot steel is quenched in oil, the oil in contact with the steel is immediately vaporized. If

the oil is heavy and sluggish, the flow of fresh oil to take the place of that vaporized will be slow. Consequently the steel is more or less surrounded with oil vapor, rather than cool oil. This means slow quenching.

The volume of the quenching bath is very important. While no definite figures can be given which will meet all conditions, it may be said that the volume should be great enough to prevent a great rise of the temperature of the bath during quenching. The size of the tank required will depend upon the size of pieces handled, the temperature of heating, the number of pieces to be quenched at one time, the production per hour, and the kind of circulating and cooling system, if any. In order to produce uniform results it is obviously necessary that the quenching bath shall be kept at the same temperature.

Circulating and Cooling Systems

For small scale hardening, a simple tank without any circulating system may be sufficient, but for large scale production some sort of cooling system is imperative. It is usually easy to provide water tanks with an inlet for fresh water and an outlet into the sewer. In this way it is possible to keep up a fast enough circulation to keep the tank at a uniform temperature. When large volumes of water are required it may pay to circulate the water between the quenching tanks and a large cistern or some cooling system.

In the case of brine and oil tanks where production is small it may be sufficient to place a coil of water pipes in the quenching tank and depend upon the circulation of water through the coil to keep the tank cool. Some cooling may be produced by simply having the oil tank placed inside a larger water tank. This is not very efficient, as there is a large amount of oil in the tank in proportion to the cooling surface of the sides of the tank.

For cooling the oil outside of the quenching tank there are two common types of cooling systems. In one of them the oil is passed through a coil of pipes placed in the tank of cold water. When this system is used, it is well to have the oil pipes numerous and small in diameter, rather than large and few. It must be remembered that the larger the cooling surface in proportion to the volume of oil, the more efficient will be the cooling.

In the other system, small streams of oil are passed over a coil of water pipes. In one such an installation the cooling system was placed on the roof of the heat treating building. The oil was screened and pumped into a large horizontal pan with a perforated bottom. It then flowed through the small holes in the pan, down over the coils of water pipes which were also horizontal, into another pan beneath the coil and thence down to the quenching tanks. The advantage of this system was that the oil was broken up into thin films, passing over the water pipes. This offered the maximum cooling surface in proportion to the volume of oil. In such a system the water pipes should be comparatively large in diameter (2 inches, for example). This system required a minimum amount of water in proportion to the oil handled. A somewhat similar home-made system, of which the writer has heard, employs a number of automobile radiators placed one above the other in a slanting position. The oil passes through the air spaces in the radiators.

No matter what system is used, it should be remembered that oil should be cooled to a certain desired temperature, not made as cold as possible. Exactly what this temperature should be will depend upon the oil used and the quenching speed desired. It probably should not be lower than 70 nor higher than 120 degrees Fahr. The temperature should be controlled as accurately as practicable.

In brine systems it may be desirable to maintain the quenching bath at lower temperatures, since brine is only recommended where quenching in cold water is not sufficient. Ammonia or other similar refrigerating systems are sometimes used in cooling brine. The same systems may be used in cooling oil but it may be questioned whether they are necessary.

In any circulating system it is important that the pumps be protected with screens, and suitable clean out traps. The overflow pipe is usually near the top of the quenching tank, but there is usually a drain pipe near the bottom. It is probably best that it should not be at the very bottom, as there is a gradual accumulation of scale in the bottom of the tank. It is obvious that the pumps and the pipes must be of sufficient size to keep the quenching bath at a constant temperature. Yet failure to make ample provisions in this respect is a common error.

When very large pieces or a large quantity of work is to be quenched in oil, it may be well to provide an extra pump which can be cut into the circulating system on a moment's notice. A few years ago a very bad fire was caused by a break down of an oil pump while there was a large quantity of hot steel in the quenching tank. An extra pump and a smother cover for the tank have since been provided.

Speed of Circulation

The discussion of circulation thus far has been limited to maintaining the quenching bath at the desired temperature. It must be remembered, however, that the speed at which the steel cools depends upon the speed of circulation of the quenching medium around the steel. Extremely rapid cooling may be produced by quenching the steel in a stream of water moving at considerable speed. This so-called "pressure quenching" has been used to advantage in the heat treating of low carbon steels. It was formerly considered that the tensile strength of low carbon steel could not be increased by quenching, but this has been accomplished by the pressure quench. Pressure sprays have also been used in other types of quenching.

The use of an air hose to stir up the quenching bath has been practiced for years, but the method is open to criticism, as it introduces bubbles of air into the bath. Air is a slower cooling medium than either oil or water. Mechanical agitators (which look like motor boat propellers) are more preferable for producing a rapid circulation of the quenching medium in the tank. By the use of such agitators in oil tanks it is said to be possible to produce any speed of cooling, from the normal speed of oil quenching up to the speed of quenching in still water. When a faster speed of cooling than ordinary oil quenching is desired this method is much preferable to the use of a very light oil with a high fire risk.

Warm Water Quenching

Warm water quenching also produces a speed of cooling intermediate between oil and cold water quenching. As in other schemes of quenching, it is necessary that the bath be kept at

a constant temperature. This can be accomplished by equipping the quenching tank with both steam coils and cold water circulation. A thermostatic control on the steam coils will keep the water at any desired temperature, providing the circulation of water is also properly adjusted.

Special Quenching Fixtures

There are numerous special quenching fixtures for particular parts which attempt to produce uniform quenching and sometimes prevent the piece being quenched from distorting. For example, bevel ring gears are usually quenched in a special press which holds the gear under pressure between dies while it is submerged in the quenching tank.

Round bars are sometimes rolled into the quenching tank. As the bars are continually turning over they are cooled uniformly. There are also special machines which rotate shafts between rollers while they are being quenched. Leaf springs are sometimes formed and quenched in special presses. Numerous special jigs have been made for specific uses. Many of the devices are covered by patents.

Conveyor Quenching

In large-scale production work the use of conveyors in quenching tanks is often advisable. Sometimes the work is spouted from the furnace into the quenching tank and allowed to drop through the bath onto the conveyor in the bottom of the tank. The conveyor then carries it slowly through the tank and up over the end and drops it into a crate or disposes of it in some other suitable manner. This method of quenching has the advantage that a large number of pieces are not allowed to collect in one place. Also the pieces are kept constantly moving through the quenching bath, which aids the cooling. Sometimes agitators or pressure jets are arranged so as to produce a rapid circulation of the quenching medium over the conveyor.

There is also a quenching machine on the market which consists of a rotating barrel with a screw inside. This barrel is placed in a slanting position in the quenching tank so that the charge end is at the bottom of the tank while the discharge end

projects over the end of the tank. The work is spouted into the hopper leading into the barrel. A jet of water meets the work as it passes into the machine. The rotation of the barrel and the screw keeps the work in constant motion and conveys it through the tank and finally out. Such a quenching device can obviously be applied only to certain classes of work, but it is said to be very efficient in producing uniform quenching of small parts on a large scale.

Some large heavy parts must be conveyed into the quenching tank as well as out of it. This is a problem to be worked out for each individual part or kind of parts. Both electric and pneumatic hoists are used in handling certain classes of heavy work.

Quenching Baskets and Fixtures

There will probably always be a great deal of quenching for which special machines and conveyors are not practicable. In these cases the quenching tanks may be supplied with baskets. These are usually made of heavy wire screen suitably re-enforced. Preferably they should be supported a little above the bottom of the tanks. Unless the baskets are very small an overhead hoist should be supplied for removing the baskets. The basket may be arranged so that either one side or the bottom can be opened for unloading.

One type of basket sometimes used for small work has a number of slanting baffle plates placed one beneath the other, slanting in from opposite sides of the basket. The work slides down the first baffle, drops onto the second baffle at the other side of the basket, slides down onto the next baffle and so on to the bottom. A dumping hopper is provided at the bottom. This requires a deep tank. Work can be spouted into such a basket fairly fast, as the pieces have considerable travel and are fairly cold before they reach the hopper at the bottom.

For parts which are to be partially quenched suitable racks may be supported across the top of the basket or tank. These racks are designed so that the pieces will be immersed to the desired depth in the quenching bath. Obviously the pieces must be placed in the racks one at a time by hand.

For shrinking large rings and similar circular parts which are oversize a fixture may be placed across the top of the tank

which will rotate the ring in a vertical position so that the outside only is immersed in the water.

It will be obviously impossible to discuss all possible devices for quenching. It is hoped that the typical examples selected will be helpful.

Straightening

Certain classes of work must necessarily be straightened after heat treating. This work often does not belong to the heat treating department. On the other hand some parts can be much better straightened when hot. In such cases it may be well for the straightening to be done immediately after tempering, the straightening presses being convenient to the tempering furnace. In some tool hardening the tools are removed from the quenching tank as soon as they have cooled to the boiling point of water. They are straightened while still warm and are then tempered.

Washing

Washing and cleaning of work which is quenched or tempered in oil is usually a function of the heat treating department. Solutions of soda, trisodium phosphate and various cleaning mixtures are used for this purpose. Lye may be used in extreme cases, but is rather objectionable to the workmen. The washing solution should be followed by a clear water rinse. Either a simple washing kettle or a power spray washing machine may be used.

If the work is to be tempered in an electric furnace it is best to wash immediately after the final quench before tempering. If tempered in oil the washing must be done after tempering. In the latter case the work should be withdrawn from the oil tempering pot and washed immediately before it cools down. In any case the washing solution should be kept hot.

Cleaning Rough Work

The scale is usually removed from rough forgings and castings by pickling, tumbling or sandblasting. These operations cannot be discussed in detail herein.

For pickling, sulphuric acid or "nitre cake" solutions are used. Both the temperature and the concentration of the solution

should be carefully regulated. Sometimes a "control" is added to prevent the solution from attacking the metal beneath the scale. Where production warrants their use, special pickling machines which agitate the work in the pickle tanks are advantageous.

Tumbling barrels ("rumblers" or "rattlers") simply tumble the work over and over and knock the scale loose. Balls, stars, and other hard pieces are sometimes placed in the barrels with the work to aid in the cleaning. Wood blocks and sawdust have been similarly used.

The simplest form of a sand blast delivers sand and air under pressure through a nozzle which is held by the operator. There are also several types of sand blasting machines which will clean certain classes of work. The sand blast is used for both rough and finished work.

Wire Brushing

Many prefer to use power driven wire brushes for cleaning gears and some other kinds of finished work. When these are used the work must come through the heat treating department fairly clean, as there is a limit to the amount of cleaning which can be done with a brush wheel.

General Layout of a Heat Treating Department

There is, necessarily, so much difference between heat treating departments handling different classes of work that a general description of a modern heat treating department becomes rather difficult. However, the day is past when heat treating is a crude side line for the blacksmith. The dark, poorly ventilated, hot room with a clay floor, is no longer considered suitable quarters for a heat treating department. The design of a modern heat treating department requires as much thought and as much engineering brains as that of any department in the factory.

The heat treating department should be clean, cool and well ventilated. The furnaces should be insulated, so that heat losses are kept down to the minimum. Proper hoods should be provided for carrying off fumes. Furnaces should be regulated so as to eliminate smoke. Some of the modern heat treating departments are painted white, or at least a very light color, which has

a good psychological effect on the workmen. Naturally the department should have a good floor, which should be kept clean.

The furnaces and the quenching tanks should be arranged so that the work can be handled as conveniently as possible. Crowding together of the furnaces should be avoided, as better work can be obtained if the workmen have comfortable working conditions. Suitable aisles should be marked off and kept clear.

As far as possible, all operations should be automatically performed. On large scale production work conveyor systems can sometimes be employed which will take care of most of the handling. In any event the equipment should be arranged so that there is a flow of work through the department without any back tracking. This is very important, not only because it cuts down the cost of handling, but because it eliminates the possibility of any work getting out of the department before all of the operations have been performed. For the same reason work from different operations should never be piled in the same place. It would be very easy for a trucker to mistake and take pieces from the wrong pile. Sometimes such an error would be caught in inspection. On the other hand, the hardness before and after a low tempering operation is often the same, so the inspector cannot tell whether the work has been tempered or not. This is not the only case in which partially treated work might pass inspection, and still be unsuitable for service.

Sometimes two or three furnaces performing consecutive operations are placed in a tandem position, and the work is automatically conveyed through the group. For example, this may be worked very well on parts which are to be normalized, hardened and tempered. This works very well when there are two or more groups of furnaces performing the same operations. A break down of any one of the furnaces in a unit stops the production of the entire unit. When there is only one group of furnaces performing one set of operations, it may be well to arrange the furnaces so that they can be used individually or as a group. For example, if the hardening and tempering furnaces are placed side by side, so that the charging end of the tempering furnace is beside the discharge end of the hardening furnace, it is possible to pass the work through hardening furnace, into the quenching tank, and then through the tempering

furnace. If both furnaces are provided with quenching tanks either furnace can be used for both operations in case it is necessary to shut down the other furnace. This would decrease but not stop production.

In some cases it is well to have the pyrometers near the furnaces where they can be watched by the furnace operator. On the other hand, in a heat treating department operating a number of automatically controlled furnaces it may be advisable to have a central control station which contains all of the pyrometer recorders and controllers. This station should be under the control of a competent pyrometer man. For lead pots and other furnaces which change in heat rapidly even though the furnaces are automatically controlled it may be well to have deviation meters or light signals or both within the furnace operator's vision which will tell him when the furnace is up to temperature.

Personnel of the Heat Treating Department

The heat treating department must be in charge of a competent foreman who understands heat treating problems and knows how to handle both men and equipment. He should know how to keep up the quality of his work and keep down the costs. In some of the larger plants the heat treating department is under the supervision, or at least has the advice of a metallurigst. He must be a practical man, not a theorist. A metallurgical department with a well equipped laboratory can be of great assistance in working out heat treating problems.

Someone must be responsible for working out the proper heat treatment for every part, for the setting of the controllers, the time cycles, for the regulation of the quenching bath temperatures, speed of circulation, etc. The maintenance of heat treating equipment is no small task in itself. While inspection is usually the function of another department, the foreman or someone in the heat treating department should be in close touch with inspection and correct errors in the heat treating department before many incorrectly treated pieces get through. In some cases it is necessary to vary the tempering temperatures, so that the steel will fall within the specified hardness limits. In these cases preliminary tests must be run either in the laboratory or

in the heat treating department on each lot of steel to determine the correct tempering temperature.

In some cases of heat treating, particularly in fine tool hardening, it is advisable that the individual operator be a skilled hardener. In some classes of production heat treating this is not necessary. The operator should, however, be intelligent and conscientious and should take a pride in his work.

Conclusion

In conclusion let it be said that while the steel mill produces the steel with its inherent possibilities, the forge shop and the foundry produce the rough shape, the machine shop produces the size and finish to a nicety, it is left to the heat treater to produce the physical properties upon which depend the ultimate success or failure of the part in service. What work can be more important or dignified than that of the heat treater? What work is worthy of more study?

* * * *

This is the end of our discussion of steel and heat treatment, and yet the foregoing is only an introduction to a science which is absorbing the thought of many men. These articles have been written primarily for the benefit of the man who has had little previous training in metallurgy. The writer leaves the work with some regret, but with the hope that he has been able to explain some of the fundamental principles and some of the technical terms, so that the reader will be better able to work out his own problems, cooperate with his heat treater and metallurgist, and better enjoy and profit by the meetings of the American Society for Steel Treating and the discussion of steel and heat treatment in the Transactions and in other books and technical journals.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
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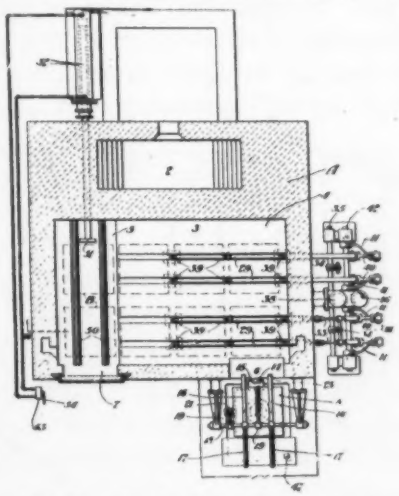
1,678,300, July 24, 1928, Sheet-Heating Furnace, John W. Perry, of Wheeling, West Virginia.

This patent describes a sheet heating furnace including a combustion chamber 2 and a heating chamber 3 having a heating floor 4 and a stacking and a soaking floor 5. In operation, the sheets to be treated are placed upon the platform 8 opposite the entrance 6 where a mechanism



is provided to automatically feed the sheets onto the heating floor 4, where pushers 29 advance the sheets longitudinally of the heating floor toward the stacking floor 5 onto the stacks B from which they may be discharged from the furnace by means of the plunger 51 and the cylinder 52.

1,680,058 and 1,680,161, August 7, 1928, Addition Material for Ferrous Metals, Paul D. Merica, of New York, N. Y., and Thomas H. Wickenden, of Roselle, New Jersey, Assignors to The International Nickel Company, of New York, N. Y., a corporation of New Jersey.

These patents describe a method and composition to facilitate the alloying of nickel and other elements to cast iron or steel and the purpose of the inventions is to provide an alloying composition containing nickel which will have a melting point substantially as low as that of cast iron. The melting point of the nickel is preferably reduced by combining therewith, previous to the addition of the nickel to the cast iron bath, carbon and silicon in percentages of 0.25 to 2.5 per cent of carbon and from 1 to 10 per cent of silicon, and in addition the desired percentages of other alloying materials, such as aluminum, chromium, man-

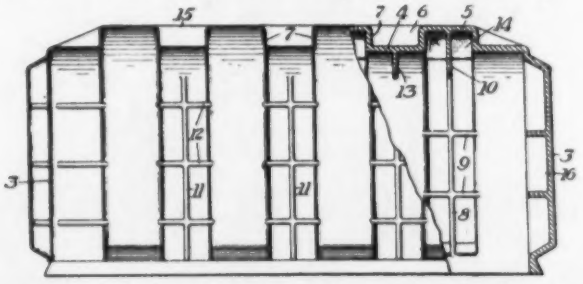
ganese, copper, tungsten, molybdenum, phosphorus and sulphur. The use of such an alloying material reduces the tendency toward blow holes in the casting and prevents segregation on account of incomplete melting of the nickel.

1,677,420, July 17, 1928, Manufacture of Iron, Mark G. Woodman, of Chicago, Illinois, Assignor of One-Third to David G. Fisher, and One-Third to Vivian F. Shantz, Both of Chicago, Illinois.

This patent claims that the grain structure and texture of cast iron can be changed from coarse to one which is uniformly fine and close and the hardness of the iron increased by the addition to the castings of 2½ pounds of salicylic acid to each ton of iron.

1,678,452, July 24, 1928, Annealing Box, William E. Troutman, of Pittsburgh, Pennsylvania, Assignor to Duquesne Steel Foundry Company, of Pittsburgh, Pennsylvania, a corporation of Pennsylvania.

This patent describes an integral cast annealing box consisting of a rectangular frame 3 having outwardly and inwardly extending cor-



rugations 7 connected by webs 4 and 5 and having longitudinal and transverse ribs 8, 9, 10, 11 and 12 in said corrugations.

1,678,776, July 31, 1928, Metal Pickling, James H. Gravell and Alfred Douty, of Elkins Park, Pennsylvania; said Douty Assignor to said Gravell.

This patent describes a pickling solution containing a material which selectively controls the bath to restrain its action on a true metal without hindering its scale removing properties. A sulphuric acid bath is used containing stannous tin and sulphite pulp waste liquor.

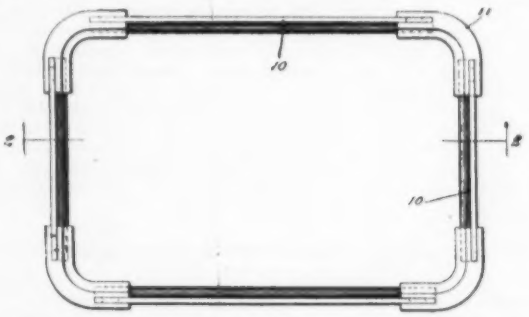
1,680,045 and 1,680,046, August 7, 1928, Method of Treating Copper Alloys and Improved Product, Victor O. Homerberg, of Belmont, Massachusetts, and Dexter N. Shaw, of Philadelphia, Pennsylvania.

These patents describe a method of treating copper alloys to produce predetermined characteristics of tensile strength, hardness or ductility, according to the result desired. The characteristic feature of the method is a double heat treatment with intermediate quenching, the first heat treatment being at a relatively high temperature while the temperature of the second heat treatment is lower and varies with the characteristics desired in the finished product. The process is particularly valuable for the treatment of 60-40 brass and similar compositions. According to the process, the alloy is heated to above the critical temperature to pro-

duce a single solid solution and quenched to preserve the solid solution at room temperature and then reheated to a temperature which will give a structure corresponding to the properties desired and cooled to retain this structure at room temperature.

1,679,510, August 7, 1928, Box for Use at High Temperatures, Edward P. Van Stone, of Reading, Massachusetts, Assignor to General Alloys Company, of Boston, Massachusetts, a corporation of Massachusetts.

This patent describes an annealing box comprising a rectangular frame having sheet iron side walls 10 provided with corrugations running par-



allel to the top and the bottom of the box with cast corners 11 interlocking with the side walls 10 to produce an annealing box which will resist the strains of alternate heating, cooling in annealing.

1,681,123, August 14, 1928, Molybdenum Alloying Compound, 1,681,124, August 14, 1928, Process of Manufacturing Molybdenum Alloying Compounds, Emil A. Lucas, of Washington, Pennsylvania, Assignor to Molybdenum Corporation of America, of Pittsburgh, Pennsylvania, a corporation of Delaware.

These patents describe a composition of molybdenum for alloying the same with iron or steel and a process of producing the same. The composition consists of a coherent molybdenum compound which, when introduced into the molten bath of metal, is readily and quickly reduced and the molybdenum content brought into thorough contact with the molten metal. The composition comprises a fused coherent mass having a low fusion point as compared with the metal to which it is to be added and contains molybdenum combined chiefly with oxygen, the molybdenum oxides being preferably lower in oxygen content than molybdenum trioxide. The composition melts quickly in the molten steel, due to its low fusion point and being quite fluid, spreads readily and disseminates the molybdenum throughout the molten metal. A fluxing agent is used to prevent sublimation of the molybdenum trioxides present. The composition includes molybdenum and a fluxing agent, such as lime, iron oxide, magnesia, silicate or fluoride, with small quantities of aluminum. The composition is prepared by roasting molybdenite to remove the sulphur content and then fusing the roasted body with the fluxing agent in the presence of a reducing agent to form a coherent fused mass suitable for addition to the molten bath.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each week with a specially prepared section of The Engineering Index Service. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the Weekly Card Index Service of the Index published by the A. S. M. E.

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ABRASIVES

SPECIFICATIONS. Coated Abrasive Data Prepared. *Abrasive Industry,* vol. 9, no. 8, Aug. 1928, pp. 210-212.

United States government issues proposed master specifications for materials purchased for various Federal departments; comments and criticism invited; proposed United States government master specifications for waterproof garnet paper, artificial waterproof abrasive paper, and revision of master specifications for emery cloth.

AIRCRAFT ENGINES

INSPECTION Inspection Methods for Whirlwind Engines, H. W. Roughley. *Aviation,* vol. 25, no. 4, July 21, 1928, pp. 256-257, 296, and 298, 5 figs.

Activities of inspectors of purchased parts and rough stock at Wright Aeronautical Corp.; bar stock, forgings, and castings must be carefully inspected upon receipt; hardness tests of connecting rod and rocker arm forgings; careful inspection of valve springs; testing piston rings; physical properties of seven aluminum alloys tested; periodic layout inspections on all castings in production; ingenious inspection devices.

ALLOY STEELS

AUTOMOTIVE. Notes on the Use of Alloy Steels for Automobiles. *Mech. World (Lond.),* vol. 84, no. 2168, July 20, 1928, pp. 56-57.

Type of steels adapted for various parts of automobiles and aircraft; for parts not highly stressed and where rigidity is only factor, 0.40 per cent carbon steel will meet requirements; for parts subject to abrasion, 0.15 per cent carbon steel properly heat treated; uses of nickel steel; 18 per cent chromium or stainless steel for valves stems; trouble in heat treatment of valves.

MANUFACTURE. The Manufacture of Alloy Steel, E. C. Smith. *Foundry Trade Jl. (Lond.),* vol. 39, no. 624, Aug. 2, 1928, p. 82.

Author points out that both major processes, open-hearth and electric, deliver from furnace sufficient metal to make operation of teeming very important factor in production; problem of freezing time; blooming-mill operations; alloy steels are, commercially speaking, not capable of being fire welded.

MANUFACTURE—FURNACES. Furnace Practice in the Manufacture of Alloy Steel, E. C. Smith. *Fuels and Furnaces,* vol. 6, no. 7, July 1928, pp. 931-933.

Discussion of various processes for making alloy steel, their essentials and results obtained with each; importance of physical chemistry; open-hearth; alloy additions are made under varying conditions; electric furnace.

PROPERTIES. Investigation of Influence of Silicon and Nickel in Hardened Steel on Annealing Process (Die Anlassvorgaenge im gehaerteten Stahl und ihre Beeinflussung durch Silizium und Nickel), H. Birnbaum. *Archiv fuer das Eisenhuettenwesen (Duesseldorf),* vol. 2, no. 1, July 1928, pp. 41-47, 8 figs.

Results of tests to determine decrease of hardness with annealing of steel; influence of carbon content on annealing phenomena in hardened steel; results are not in agreement with those of Honda, but do not contradict martensite theory of Hanemann and Schrader.

TITANIUM CONTENT. Alloys of Iron with Titanium (Beitraege zur Kenntnis der

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

niederigprozentigen Legierungen des Eisens mit Titan), H. Mathesius. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 26, June 28, 1928, pp. 853-858, 13 figs.

Investigations show that titanium has favorable influence on steel; carbon-poor steel alloy with titanium is superior to ordinary carbon steels; main improvements in investigated steel were: reduction of segregation, increase of elastic limit to 80 per cent of tensile strength as compared to 55 per cent with ordinary carbons; increase of wear resistance and notch strength.

UTILIZATION — QUARRY INDUSTRIES. Use of Alloy Steels in the Pit and Quarry Industries, H. W. Munday. *Pit and Quarry*, vol. 16, no. 8, July 18, 1928, pp. 87-88.

Special steels desirable where wear and abrasion are pronounced; 7 manufacturers enumerated; distinction as contrasted with simple carbon steel; "Strenes" metal, Long-grained mottled iron alloyed with nickel and chromium, Brinell hardness averaging 405 and transverse strength about 2200 lb. per sq. in.; withstood test, in cement mill kiln, of 90 days of 24 hr. each in temperature 1200 deg.; manganese steel.

AGE HARDENING. Age-Hardening of Alloys, R. Hay. *Am. Metal Market*, vol. 35, no. 134, (2nd section), July 14, 1928, pp. 10-11 and 23.

Treats on influence of various operations on age-hardening effect; temperature, size of particle; application of age hardening. Paper presented before Scottish Local Section of Inst. on Metals.

HEAT RESISTING. Heat-Resisting Alloys, T. H. Turner. *Am. Metal Market*, vol. 35, no. 134, (2nd section), July 14, 1928, pp. 7-9, 9 figs.

Introduction of heat-resisting alloys has followed on commercial production of extraction resisting metals; investigation of position which heat-resisting materials occupy in present-day engineering design; how demand for resistance to high temperatures has been met. Paper read before Birmingham Local Section of Inst. of Metals.

ALUMINUM

ELONGATION. The Influence of Dimensions of Elongation of Aluminum (Der Einfluss des Messlaengenverhaeltnisses auf die Bruchdehnung bei Aluminum), P. Melchior. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 7, July 1928, pp. 252-257, 10 figs.

Investigations show that elongation in aluminum workpiece measured with different dimensions, fluctuate to much greater extent than in case of steel or iron; recalculation for standard German dimensions.

ALUMINUM ALLOYS

AUTOMOTIVE—RESEARCH. The Development of Aluminum for Automotive Purposes, R. S. Archer. *Soc. Automotive Engrs.—Jl.*, vol. 23, no. 2, Aug. 1928, pp. 149-160, and discussion 160-161, 17 figs.

Properties and composition of aluminum alloys in automotive industry are described; aluminum casting alloys; heat treated castings of Lynite 195 combine strength and ductility; wrought aluminum alloys; principles of weight reduction; application of alloys to pistons, connecting rods, cylinder heads and blocks, crankcases, brake shoes, wheels, tire valves, bodies and commercial vehicles, experimental aluminum car.

CASTING. Problems in Aluminum Founding, G. Mortimer. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 623, July 26, 1928, pp. 55-57.

Notes on Archbutt nitrogen process; difficulties with alloy for cylinder pistons; disintegration of ingot made from aluminum swarf; aluminum pattern plates; machining speeds of aluminum-alloy castings; test bar specification employing chill-cast test bar. Discussion of paper published in June 14 and 21, 1928, issues of same journal.

CRYSTALS. Elastic Properties of Crystals of a Heat Treated Aluminum Alloy (Festigkeitseigenschaften von Kristallen einer veredelbaren Aluminiumlegierung), R. Karnop and G. Sachs. *Zeit. fuer Physik (Berlin)*, vol. 49, no. 7 and 8, 1928, pp. 480-497, 20 figs.

Report from Kaiser Wilhelm Institute of Metals, of Berlin-Dahlem on method of production and on tensile strength, elastic limit and other properties of single crystals of heat treated aluminum alloy containing 5 per cent of copper; X-ray photographs of crystal structure.

ELECTROPLATING. Electroplating on Aluminum and Its Alloys, H. K. Work. *Metal Industry (Lond.)*, vol. 33, nos. 4 and 5, July 27 and Aug. 3, 1928, pp. 81-84 and 105-108, 11 figs.

Author gives some of reasons advanced in literature for difficulty in plating on aluminum; testing of deposits; cleaning procedures; plating on smooth surface; results of addition agents; heat treatment methods; Travers process; plating on rough surface, high and low metal dips; roughening and plating procedures; processes recommended; advantages of plated aluminum.

HEAT TREATMENT. Heat Treatment of Aluminum and Its Light Alloys, R. J. Anderson. *Fuels and Furnaces*, vol. 6, no. 8, Aug. 1928, pp. 1035-1036.

Discussion of defects in aluminum alloys due to heat treatment.

MACHINING. Rational Machining of Light Metals (Le travail rational des métaux légers). *Pratique des Industrie Méchaniques (Paris)*, vol. 11, no. 4, July 1928, pp. 153-157, 8 figs.

Defines characteristics which tools and machines should have to furnish maximum of efficiency in working light metals; lathes, milling machines, drills, taps, reamers, etc., are mentioned.

MAGNETIC PROPERTIES. Magnetic susceptibility of Aluminum (La susceptibilité magnétique de l'aluminium), C. Chéneveau. *Revue Générale de l'Electricité (Paris)*, vol. 24, no. 1, July 7, 1928, pp. 7-11.

Results of measurements of aluminum alloys; effect of iron in alloys; relation of iron content to magnetic susceptibility.

NAVAL APPLICATIONS. Characteristics and uses of Aluminum Alloys, H. N. Wallin and F. B. Olcott. *U. S. Naval Inst.—Proc.*, vol. 54, no. 8, Aug. 1928, pp. 675-682.

Uses for aluminum is discussed as applied primarily to naval vessels; specialized uses in field of aeronautics are not covered; limitations; general physical properties; forms commercially available; navy casting alloy; rolled; drawn or extruded

alloys; lists some of general shipboard applications of aluminum alloys which may be considered as typical; preservation.

SMELTING. Smelting Secondary Aluminum and Aluminum Alloys, R. J. Anderson. *Metal Industry (N. Y.)*, vol. 26, no. 8, August 1928, pp. 347-349.

Sampling of scrap lots; blending in production of secondary aluminum and secondary aluminum alloys.

ALUMINUM CASTINGS

Conditions Affect Quality of Aluminum Castings, T. W. Bossert. *Can. Foundryman (Toronto)*, vol. 19, no. 7, July 1928, pp. 12-15, 5 figs.

Necessity for accurate control in melting No. 12 alloy is discussed; effects of melting and pouring temperatures, soaking time in furnace, and history of material prior to final remelting are taken up.

X-RAY ANALYSIS. Results of X-Ray Examinations of Aluminum Pistons and Other Light Metal Castings (Untersuchungsergebnisse der Roentgendurchleuchtung von Aluminiumkolben und anderen Leichtmetall-Gusstuecken), M. v. Schwarz. *Zeit. fuer Flugtechnik u. Motorluftschiffahrt (Munich)*, vol. 19, no. 14, July 28, 1928, pp. 323-325, 13 figs.

Value of fluoroscope and X-ray photographic examinations for determination of quality of castings, detection of flaws, cavities, etc.

ALUMINUM FOUNDRY PRACTICE

Small Jobbing Shop Specializes in Aluminum, E. Bremer. *Foundry*, vol. 56, no. 13, July 1, 1928, pp. 512-516, 11 figs.

Rolle Casting Co., Philadelphia, is Eastern foundry specializing in aluminum castings; some large castings are made by firm which are described in detail; foundry well ventilated; parting line important; melting equipment consists of four pit fires, two fired by coke and two by natural gas and open-flame furnace of 350 pound capacity; most of aluminum-alloy castings are made of aluminum-silicon alloy; other alloys are used.

ALUMINUM-SILICON ALLOYS

CASTINGS. Silumin Chill Castings (Silumin-Kokillenguss), J. Dornauf. *Giesserei. (Duesseldorf)*, vol. 15, no. 29, July 20, 1928, pp. 703-709, 48 figs.

Author describes in detail production of silumin chill castings; silumin is an aluminum-silicon alloy, containing about 13 per cent silicon.

ALUMINUM STEELS

Aluminum, Chromium and Related Alloy Steels, V. O. Homerberg. *Black and White*, vol. 1, no. 4, June 1928, pp. 25-27, 3 figs.

New series of alloy steels, capable of being case-hardened by gaseous ammonia; method for adding aluminum to steel; method used in United States produces aluminum steels which are completely deoxidized.

AUTOMOBILE PARTS

NITRIDE HARDENING. Nitriding Process Is Now Employed to Harden Automobile Parts. *Automotive Industries*, vol. 59, no. 4, July 28, 1928, pp. 132-133, 2 figs.

Durable and non-rusting surface is applied to valve tappets, pump shafts, and crankshafts; nitriding consists in forming hard surface layer or case on parts made of steel of special composition by subjecting these parts to current of ammonia gas while at comparatively high temperature; less distortion of parts than in other surface-hardening processes; formation occurs quickly.

AUTOMOBILES

AXLES — TESTING. Torsional Strength Figures Given for Axle Shafts, P. M. Heldt. *Automotive Industries*, vol. 59, no. 4, July 28, 1928, pp. 120-121 and 131, 2 figs.

Results of tests on shafts of various grades of steel show moments which cause failure; elastic limits also determined by torsion testing machines; relation between shearing stress and distance from axis; figures of torsional strengths of alloy steel rear axle shafts from Chrysler Motor Corp. and Hupp Motor Car Corp.

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Blast Furnace and Steel Plant*, vol. 16, no. 7, July 1928, pp. 909-913, 2 figs.

Equipment and Methods of pickling and cold rolling steel sheets; chemical action in pickling; operation of rolls; physical changes resulting from cold rolling.

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Heat Treating and Forging*, vol. 14, no. 7, July 1928, pp. 740-746, 9 figs.

Process of annealing reviewed together with its importance and control; equipment and methods of annealing automobile sheets in single box furnaces described; action taking place within box during its anneal explains oxide border and corners present on majority of sheets for auto stampings; inspection of box-annealed sheets.

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Blast Furnace and Steel Plants*, vol. 16, no. 8, Aug. 1928, pp. 1037-1043, 9 figs.

Process of annealing sheet steel for automobile bodies is reviewed, together with its importance and control; equipment and methods of annealing in single box furnaces described; annealing and crystallization; inspection of box-annealed sheets.

BODIES—ALUMINUM STANDARDS. S. M. M. T. Provisional Standards. *Automobile Engr. (Lond.)*, vol. 18, no. 243, July 1928, p. 260, 5 figs.

Provisional standards of Society of Motor Manufacturers and Traders for use of aluminum in automobile body construction; bimetallic contacts, method of fixing aluminum painting, dopes, and condition of wood are covered.

AUTOMOTIVE LABORATORIES

MEASURING INSTRUMENTS. New Chrysler Laboratories Fitted With Ingenious Test Devices, A. F. Denham. *Automotive Industries*, vol. 59, no. 3, July 21, 1928, pp. 82-84, 5 figs.

Engineering Building at Highland Park plant of Chrysler Corp. divided into metallurgical, physical, electrical and mechanical sections; equipment of novel design; determining shock absorber characteristics and riding qualities; flow-testing carburetors and manifolds; cold room has radio loud speaker

communication with outside; influence of aircraft engine laboratory shown in many testing devices.

BEARING METALS

Where to Use the Different Kinds of Bearing Metals, J. Mehr. *Mill and Factory Illustrated*, vol. 1, no. 7, July 1928, pp. 31-33 and 78, 9 figs.

Summary of most commonly used mixtures for bearing metals and their various applications; careful selection of bearing metals will help reduce friction losses; no economy in using high-grade costly babbitt where low-grade alloy will do work.

Metals and Alloys Used for Bearings, A. Seton. *Metal Industry (Lond.)*, vol. 33, no. 2, July 13, 1928, pp. 29-30.

Cast iron and wrought iron are, in special circumstances, employed, but nonferrous metals are almost invariably preferred; copper alone is useless as bearing metal, and tin is too expensive; alloys of two, known as bronzes, are most useful and are comparatively inexpensive; effect of lead.

CASTING. Pouring and Casting of Bearing Metals. *Lubrication*, vol. 14, no. 6, June 1928, pp. 62-64, 2 figs.

Extent to which bearing can be expected to function effectively will depend upon its initial formation; melting metal; preheating of bearing parts; treatment of shells; pouring bearing metals.

PROPERTIES. Properties and Use of Anti-Friction Alloys (Les Propriétés et l'emploi des alliages antifriction). *Génie Civil (Paris)*, vol. 92, no. 17, Apr. 28, 1928, pp. 19-20.

Coefficient of friction is lower for hard than for soft metals; summarizes desirous properties of bearing metal; no single alloy possesses every desirable quality; alloys having lead base are usually suitable for high speeds, but not for shocks and forces encountered in heavy machinery; conversely, anti-friction alloys with tin base are suitable for heavy loads, but not for speeds. See brief translated abstract in Power Engr. (Lond.), vol. 23, no. 268, July 1928, p. 284.

BEARINGS

BRONZE — MANUFACTURE. Specializes in Bronze Bearings, P. Dwyer. *Foundry*, vol. 56, no. 14, July 15, 1928, pp. 558-562, 4 figs.

Layout and operation of foundry of More-Jones Brass & Metal Co., recently merged into Nat. Bearing Metals Corp.; approximately 75 per cent of 100 tons of metal melted daily is poured into bearings for cars and locomotives on various railroads; crucibles employed exclusively for handling all molten metal; wherever possible, mechanical equipment carries load; metal is melted in battery of 7 oil-fired open flame furnaces; 3 batteries of coke-fired crucible pit furnaces.

DIE CASTING. The Production of Die-Cast Bearings, K. A. Hill. *Machy. (Lond.)*, vol. 32, no. 824, July 26, 1928, pp. 530-531, 5 figs.

Description of die for mass production of die-cast crankshaft bearings, oil grooves, gutterways, oil holes and dowels being cast in; finished casting guaranteed to be accurate to 0.001 inch.

BERYLLIUM

Metallurgical Applications of Silicon and Beryllium. *Metallurgist (Supp. to Engineer, Lond.)*, July 27, 1928, pp. 106-107.

Review of U. S. Bur. of Standards Circular no. 346; both silicon and beryllium are light metals, comparable in this respect with aluminum and magnesium; densities: silicon 2.34, beryllium 1.84.

BOILER PLATES

ALLOY MATERIALS. Alloy Materials for Boiler Shells and Tubes, J. B. Romer and W. W. Eaton. *Power*, vol. 68, no. 5, July 31, 1928, pp. 195-197.

How strength, ductility, hardness and corrosive resistance of steel are effected by addition of such elements as nickel, chromium, silicon, manganese, copper, tungsten, cobalt, and molybdenum. Paper presented at Nat. Board of Boiler and Pressure Vessel Inspectors.

BRASS

OXYACETYLENE WELDING. Oxyacetylene Welding of Brass, A. Eyles. *Machy. (N. Y.)*, vol. 34, no. 12, Aug. 1928, pp. 921-923, 2 figs.

Autogenous welding with oxyacetylene torch is efficient and economical method of joining brass parts; properties according to copper and zinc content; fluxes used of similar composition to those in copper welding; welding metals used; preparation of brass and welding procedure; treatment after welding.

BRASS FOUNDRY PRACTICE

The Fundamentals of Brass Foundry Practice, R. R. Clarke. *Metal Industry (N. Y.)*, vol. 26, no. 8, Aug. 1928, pp. 341-342, 3 figs.

Description of basic laws which control melting and casting of metals and their application to practical foundry work.

BRIDGES, SUSPENSION

Notes on Recent Development in Bridge Engineering, J. Husband. *Structural Engr. (Lond.)*, vol. 6, no. 7, July 1928, pp. 216-220.

Few figures relating to physical properties of materials employed on recent bridge structures; tables give composition of various classes of nickel steel for bridge work recommended by Waddell; reference to steel used for Florianopolis bridge.

BRONZE

ALLOYS. Alloys Affect Properties, E. R. Thews. *Foundry*, vol. 56, no. 13, July 1, 1928, pp. 532-535.

Gives effect of various metallic additions such as zinc, lead, nickel, cobalt, manganese, phosphorus, silicon, etc., on casting properties of bronze; cobalt bronzes; tin replaces nickel; Brinell hardness of bronzes is increased from 63 to 71, decreasing to 60 if phosphorus content rises to 0.50 per cent.

HEAT TREATMENT. New Nickel Aluminum Bronze. *Soc. Mech. Engrs. (Japan) —Jl.*, vol. 31, no. 134, June 1928, pp. 215-233, 23 figs.

Special nickel bronze containing small per cent of aluminum in Cu-Ni alloy (Cu 90, Ni 10) is extraordinarily improved; by

special treatment; nickel bronze (Cu 90, Ni 10, Al 2) increased hardness very rapidly up to 240-180 by tempering at 600-300 deg. Cent. after quenched in water or liquid bath under 400 deg. Brief abstract in English. (In Japanese.)

CASE HARDENING

Facts and Principles Concerning Steel and Heat Treatment, H. B. Knowlton. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 300-315, 3 figs.

Discussion of common errors in case-hardening and their methods of prevention; among subjects discussed are: failure to withstand wear, spalling, cracking in hardening, cracking in grinding, breaking, distortion, and abnormal steel; cyaniding, nitriding, and steels for nitriding.

CARBURIZING. Important Factors in Case Hardening. *Black and White*, vol. 1, no. 3, Mar. 1928, pp. 12-15, 1 fig.

Carburizing plain carbon steels where important consideration is simply hard surface; selecting carburizing compound for this grade of steel; carburizing temperatures; very important that temperature chosen be maintained as constant as possible.

CARBURIZING. Carburizing and Case Hardening. *Heat Treating and Forging*, vol. 14, no. 7, July 1928, pp. 757-761, 1 fig.

Carburizing compounds used and containers employed with proper directions given for packing parts; cyanide and gas carburizing; lead and furnace treatments. From Driver-Harris Co. booklet on Nichrome Castings.

NITRATION. Steels for Case Nitrification, A. B. Kinzel. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 248-253 and discussion 253-254.

Study of effect of various alloying elements on case resulting from low-temperature nitrification; shows particularly extreme hardness and general desirability of case obtained with vanadium steel; treating surface of plain carbon steels with aluminum or vanadium and then nitrifying were investigated and satisfactory cases obtained in this way; properties of steel containing 0.4 per cent vanadium in solid solution make such steel particularly suited to industrial application.

CAST IRON

IMPROVEMENT. Manufacture of High-Grade Cast Iron (La fabrication des fontes résistantes), M. Girardet. *Société Industrielle de l'Est—Bul. (Nancy, France)*, no. 188, Jan.-Feb.-Mar. 1928, pp. 5-23, 1 fig.

Composition of mixture; action on graphite; use of single cupola; accessories to improve cupola castings; shaking hearth of Dechesne for desulphurizing of cast iron, and its mode of operation; gyratory hearth according to author's system. Bibliography.

IMPROVEMENT. Cast Iron Is Improving, E. Bremer. *Foundry*, vol. 56, nos. 13 and 14, July 1 and 15, 1928, pp. 541-543 and 545, and 569-571, 9 figs.

July 1: First castings in America in 1643 in Virginia; demand for castings that are tough and will withstand high temperatures and repeated impact; careful control needed; producing cast iron with pearlitic structure in special electric furnace; Lanz process of producing cast iron. July 15: Use of heated molds; method of casting in 1851; manufacture of Diesel engine castings; special cast iron developed by Meehan; alloy cast irons used in making heavy-duty castings.

IMPROVEMENT. High-Grade Cupola Cast Iron (Hochwertiges Kupolofengusseisen), F. Dengler. *Zeit. fuer die gesamte Giessereipraxis (Berlin)*, vol. 49, nos. 28 and 29, July 8 and 15, 1928, pp. 237-240 and 245-247, 3 figs.

Discussion of methods of desulphurization; graphite separation.

IMPROVEMENT. Recent Developments in High-Test Cast Iron, R. Moldenke. *Am. Mach.*, vol. 69, no. 6, Aug. 9, 1928, p. 226.

Description of how recent improvements in cast iron have given machine builder a cast iron having double tensile strength of gray iron, retaining excellent machining qualities, and adapted for machines subjected to severe service.

IMPROVEMENT. The Production of High-Grade Cast Iron (Die Herstellung hochwertigen Gusseisens, ihre metallurgische Grundlage und die praktische Ausfuehrung), B. Osann. *Giesserei (Duesseldorf)*, vol. 15, no. 27, July 6, 1928, pp. 648-655, 7 figs.

All processes for improvement of cast iron have as their aim development of eutectoid composition; critical evaluation of iron-carbon diagrams; authors emphasize metallurgical aspect of cast iron manufacture; problems of graphitization and flake formation; recommendation for production of eutectoid cast iron in reverberatory furnace and cupola.

HEAT TREATMENT. Heat Treatment of Gray Iron, E. E. Marbaker. *Iron Age*, vol. 122, no. 5, Aug. 2, 1928, pp. 282-285, 2 figs.

Strains in gray iron castings may be relieved by heating at moderate temperatures; castings may be softened without weakening by annealing above critical point, held for sufficient time to insure thorough heating, and then cooled slowly at least through first 100 deg.; castings hardened again after machining, by reheating, quenching, and tempering to desired hardness.

NICKEL. 200 Years' Experience Backing Production of Nickel Cast Iron. *Inco*, vol. 8, no. 2, pp. 14-15 and 18, 5 figs.

Brief description of recent work of Cresson-Morris Co., Philadelphia; nickel alloys made by this company are not limited to pressure castings but go into many other castings that are used for various purposes; company finds nickel an economy in 75 per cent of their work.

PEARLITIC. Advancements in Cast Iron Quality Show Definite Progress, E. E. Marbaker. *Foundry*, vol. 56, nos. 15 and 16, Aug. 1 and 15, 1928, pp. 613-615 and 657-660, 4 figs.

Aug. 1: Methods employed in production of cast iron with pearlitic structure; formation of such structure throughout all sections is said to be desirable, and is associated with low carbon contents and suitable cooling methods; effect of silicon content important. Aug. 15: Essential points given in patents for manufacture of cast iron with pearlitic structure according to Lanz and Emmel; data on physical properties of these irons.

CASTINGS

CLEANING. Cleaning Room Progress Aids

Production of Quality Castings, F. G. Steinebach. *Foundry*, vol. 56, no. 15, Aug. 1, 1928, pp. 636-637, 2 figs.

Process of pickling castings is described; solutions used; pickling equipment; construction of pickling tanks; methods of heating tanks; equipment for dipping castings into pickling solution.

TESTING. The Testing of Castings. *Metallurgist (Supp. to Engineer, Lond.)*, July 27, 1928, pp. 97-98.

Discusses question of best form of simple mechanical test for casting test bar; considerations suggest use of separately cast standard test bar tested in simple manner for routine reception purposes, coupled, as soon as may be, with series of careful correlations between test bar results and behavior of typical full size castings when tested to destruction.

CHAINS

WROUGHT IRON—FAILURE. The Causes of Failure of Wrought Iron Chain and Cable, H. J. Gough and A. J. Murphy. *Quarry and Surveyors and Contractors Jl. (Lond.)*, vol. 33, nos. 377 and 378, July and Aug. 1928, pp. 254-258 and 293-295, 1 fig.

In 1924 experimental investigation was commenced at National Physical Laboratory; lengthy research program has been completed and full report is in course of publication; shorter account of results of research in present paper; overheated wrought iron; faulty welds; effect of repeated static straining; investigation of chains drawn from service. From paper read before Instn. Mech. Engrs.

CHROMIUM-COPPER STEEL

The Development of High-Grade Structural Steel (Zur Fortentwicklung des hochwertigen Baustahles), E. H. Schulz. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 26, June 28, 1928, pp. 849-853, 4 figs.

Discussion of development and properties of structural steel; strength, corrosion resistance, and technological properties of new chromium-copper structural steel with 0.5 to 0.8 per cent copper, 0.4 per cent chromium, and 0.15 per cent carbon, having strength properties of silicon steel with 1 per cent silicon.

CHROMIUM PLATING

Chromium Plating Growing. *Abrasive Industry*, vol. 9, no. 8, Aug. 1928, pp. 221-222, 1 fig.

Operation necessitates intense currents and also heating the bath; principal arrangements; impossible to immediately adapt existing electroplating installation to chromium plating; cost of process is high; no metallurgical development has made greater progress of late than chromium plating.

Chromium Plating (Le chromage electrolytique), J. Cournot. *Société des Ingénieurs Civils de France—Compte Rendu Des Travaux (Paris)*, vol. 81, no. 3-4, Mar.-Apr. 1928, pp. 303-311.

Describes principle of plating process; advantages of chromium plating; difficulties of execution; applications of electroplating.

CHROMIUM STEEL

STRUCTURE. The Internal Structure of Chromium Steel (Ueber den inneren Aufbau der Chromstaehle), E. Maurer and H. Nienhaus. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 30, July 26, 1928, pp. 996-1005, 12 figs.

Review of literature on carbides contained in chromium steel; conversion into solid state; tests were carried out on a series of 22 chromium-iron-carbon alloys; indication of occurrence of double carbides was not shown of physical investigation.

CORUNDUM

OCCURRENCE AND USES. Corundum, C. J. N. Jourdan. *Chem., Met. and Min. Soc. of S. Africa (Johannesburg)*, vol. 27, no. 10, Apr. 1928, pp. 230-235 and (discussion) 235-236.

Discusses world occurences, composition, properties, production, trade specifications, mining and grading, market prospects, etc., with particular reference to abrasive industry; casual mention of oriental emerald, sapphire and ruby as corundum gem stones; emphasizes existence of extensive deposits in Transvaal and possibilities of establishing local industry.

COPPER CASTING

The Production of Large Copper Castings (Moulage de grosses pièces en cuivre). *Fonderie Moderne (Paris)*, vol. 22, June 10, 1928, pp. 219-222, 7 figs.

Describes molding and casting of copper and its action when in molten state; shrinkage after cooling and effect on castings; pouring from top and bottom.

COPPER

X-RAY ANALYSIS. Study of Structure of Electrolytic Copper by X-Rays (Etude de la structure des cuivers électrolytique au moyen des Rayons X), J. J. Trillat. *Revue de Métallurgie (Paris)*, vol. 25, no. 5, May 1928, pp. 286-288, 4 figs.

Determination of structure and grain size by use of X-ray apparatus and results obtained by this method. Bibliography.

COPPER ORE

MICROSCOPY. Experiments Bearing on Bornite - Chalcocite Intergrowths, G. M. Schwartz. *Economic Geology*, vol. 23, no. 4, June-July 1928, pp. 381-397, 12 figs.

Discussion of mineral texture, supplementing previous paper on "Intergrowths of Chalcopyrite and Cubanite," as published in same journal, vol. 22, 1927, pp. 44-61.

CRANKSHAFTS

STIFFNESS CALCULATION. An Empirical Formula for Crankshaft Stiffness in Torsion, B. C. Carter. *Engineering (Lond.)*, vol. 126, no. 3261, July 13, 1928, pp. 36-39, 2 figs.

Formula put forward was evolved from results of stiffness tests on crankshafts of marine, aircraft, and automobile types; in all cases shafts were twisted in bearings with clearances approximating to those used in ordinary working, and all stiffness relate to transmitted torque.

CUPOLA PRACTICE

IMPROVEMENT. Cupola Operations Are Changing. *Iron Age*, vol. 122, no. 3, July 1928, p. 148.

Improvements in cupola practice of thermotechnical and metallurgical nature; cooling

of reduction zone expected to improve thermal economy; desulphurizing by alkaline slags; effect of cooling reduction zone; water spray lowers coke consumption; Schuermann cupola passing out; characteristics of high-test iron.

DIE CASTING

Nature, Production and Uses of Die Castings, S. Tour. *Am. Metal Market*, vol. 35, no. 134 (2nd section), July 14, 1928, pp. 18-19.

Process; casting machines; dies; cost of castings; structure; production; uses; production practice in alloys; list of alloys agreed on for die-casting investigation, with nominal compositions desired.

PRACTICE—EUROPE. Notes on European Die Casting Practice, E. V. Pannell. *Am. Metal Market*, vol. 35, no. 134, (2nd section), July 14, 1928, pp. 21-23.

Machines for heavy alloys; light alloy practice; air and plunger machines; standardization; descriptive articles published 1922-1927 on die casting in Europe.

DIES, CAST IRON

FORMING AND BENDING. Cast Iron Dies for Forming and Bending, P. H. White. *Machy. (N. Y.)*, vol. 34, no. 12, Aug. 1928, pp. 925-926, 1 fig.

Dies made of cast iron are suited for simpler bending and forming operations where work is more of direct bending or compressing nature, rather than drawing action which may cause abrasion of wearing surfaces: advantages of cast iron dies and use in experimental work.

DURALUMIN

Duralumin (El Duraluminio). *Boletin de la Sociedad de Fomento Fabril (Santiago)*, no. 5, May 1928, pp. 275-277.

Aluminum is lightest of metals of approachable price, but in pure state has certain defects that limit its use; most interesting alloy is duralumin; density 2.75 to 2.85; limits of chemical composition; essentially aluminum, copper, manganese and magnesium; iron and silica, considered as impurities, should be less than 0.6 per cent each; lead and tin objectionable; amenable to arc or oxyacetylene welding; riveting; heat treatment; forging; annealing; machining; mechanical characteristics.

ELECTRIC FURNACES

HEAT TREATING. Electric Annealing and Normalizing, at Timken Plant, M. T. Lothrop. *Elec. World*, vol. 92, no. 5, Aug. 4, 1928, pp. 201-204, 8 figs.

Satisfactory experience with electric furnaces for heat-treating alloy steels leads to 3600-kw. installation with 1850 kw. for electric normalizing and annealing.

HEROULT. Electric Steel Plant of the Saint Jacques Works (L'aciérie électrique des usines Saint-Jacques). *Jl. du Four Electrique (Paris)*, vol. 37, no. 7, July 1928, pp. 205-208, 4 figs.

Describes in detail Heroult furnace installed at Montlucon; 3-phase type with 3 vertical electrodes; electrode regulators and electric equipment; operation and thermal efficiency.

HIGH FREQUENCY. The High Frequency Electric Furnace (Le four électrique à haute fréquence). *Jl. du Four Electrique (Paris)*, vol. 37, no. 7, July 1928, pp. 209-212, 3 figs.

Article describes the Northrup furnace and its operation; uses in United States, England and France, operation of furnace; advantages of high frequency are explained.

LABORATORY — HIGH TEMPERATURE. Furnaces of Tungsten and Zirconium Oxide (Ueber Wolframonoxydoefen), W. M. Cohn. *Zeit. fuer Technische Physik (Leipsic)*, vol. 9, no. 3, 1928, pp. 110-115, 3 figs.

Description of tube furnaces made from tungsten wire wrapped on formers of zirconium oxide; mode of construction is discussed in detail and drawings of typical furnaces given; they can be used to about 2000 deg. Cent.

INDUCTION. The Coreless Type Induction Furnace, N. R. Stansel and E. F. Northrup. *Heat Treating and Forging*, vol. 14, no. 7, July 1928, pp. 787-788, 791 and 794, 6 figs.

Action of coreless-type induction furnace on molten charge and ability to melt rapidly are explained; range of melting application; construction of furnaces for various purposes; provisions for tapping; applications in existing installations are given.

LABORATORY. Laboratory Uses for an Electric Crucible Furnace. *Am. Paint and Varnish Mfrs.' Assn.—Sci. Sec.*, cir. no. 335, July 1928, pp. 609-611, 1 fig.

Laboratory has had prepared electric furnace which has been found useful for heat test for tung oil.

POWER FACTOR. Determination of Power Factor of an Electric Arc Furnace (Détermination du facteur de puissance d'un four à arc), M. Mathieu. *Arts et Metiers (Paris)*, vol. 81, no. 94, July 1928, pp. 266-269, 5 figs.

Determination of power factor by numerical and graphic calculation.

THREE-PHASE. Arrangement for Supplying Current to Large Electric Three-phase Furnaces (Stromtilforselarrangement ved store elektriske 3-fase ovner), A. Weber. *Elektroteknisk Tidsskrift (Oslo)*, vol. 41, no. 11, June 15, 1928, pp. 217-220, 5 figs.

Various changes in arrangement of conductors; formulas for calculation of effect; requirements for remedying mutual induction; importance of combating self-induction of phases; illustrations of arrangements.

ELECTRIC HEATING

INDUSTRIAL. Industrial Electric Heating, O. Wilhelmy. *Elec. Light and Power*, vol. 6, no. 8, Aug. 1928, pp. 60, 62 and 64-65, 4 figs.

Details as to variety of applications; firing glassware; embossing press heating; sand mold driers electrically heated; heating fuel oil by electricity; brass melting; automobile heating.

TUBULAR—GREAT BRITAIN. Tubular Electric Heating System Used in Great Britain, A. C. Blackall. *Heat. and Vent. Mag.*, vol. 25, no. 8, Aug. 1928, pp. 70-71, 3 figs.

New method of electric heating recently developed by Young, Osmond and Young, London, known as unity tubular electric

system; provides large heating area, working at low surface temperature approximately that usual in conventional water systems; description and operation of apparatus.

WIRE TESTING. Metallic Elements for Electrical Heating. *Metal Industry (Lond.)*, vol. 33, no. 1, July 6, 1928, p. 10.

Review of report of Committee B.4 of Am. Soc. Testing Matls., which proposes tentative method for chemical analysis of sulphur by evolution - titration method; based on (1) evolution of practically all sulphur in alloy as hydrogen sulphide when alloy is dissolved in HCl (specific gravity 1.19); (2) absorption of evolved gas by means of ammoniacal solution of cadmium chloride; and (3) determination of sulphur by titration with standard solution of potassium iodate; sample of nickel-chromium wire was analyzed by three methods.

FORGINGS, STEEL

HEAT TREATMENT. Heat Treatment of Forgings and Castings for Selective Directional Adjustment of Residual Stresses, W. J. Merten. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 193-198, 3 figs.

Methods of selective abstraction of heat or selective cooling by directed quenching for producing favorable directional internal or residual stresses in forged disks or cast parts of rotating bodies; directing of coolant upon middle of rotating hollow bored or forged disk by properly placed spraying nozzles or by enclosing red-hot disk in container, immersing same into coolant and simultaneously opening ports and rotating disks.

FOUNDRY PRACTICE

British Association Celebrates 25 Years of Progress, V. Delport. *Foundry*, vol. 56, no. 14, July 15, 1928, pp. 590-592.

Review of convention of Inst. of Brit. Foundrymen at Leicester with brief abstract of papers; "Malleable Castings," W. T. Evans and A. E. Peace; "Shrinkage in an Iron Casting," M. Servais; "Steel Castings for Severe Service," J. H. Hall; "The Cohesibility of Rammed Sand," M. Faulkner; "Iron Foundry Castings," W. R. Wintle.

Welding Facts and Figures, D. Richardson and E. W. Birch. *Welding Jl. (Lond.)*, vol. 25, no. 297, June 1928, pp. 169-172, 5 figs.

Pressing example of toggle drawing press; illustrates manufacture of metal balls from single strip of metal, balls being free from seams, joints, or plugs; casting and die casting; mold castings; sand used for molds.

SPECIALIZATION. How Foundry Orders Are Affected by Specialisation, W. J. Hiscox. *Iron and Steel Industry (Lond.)*, vol. 1, no. 11, Aug. 1928, pp. 333 and 352.

Specialization in foundry has brought about change in composition of regular customer; he is regular only in respect to specific castings; buyer gains by spreading orders instead of placing them in one foundry; specialization enables foundry to develop its resources and do itself justice; how foundry may keep its regular customers.

FURNACES

ANNEALING, GAS-FIRED. Top-Fired Annealing Furnaces, O. P. Luetscher. *Iron Age*, vol. 122, no. 4, July 26, 1928, pp. 211-212, 3 figs.

Set of annealing furnaces in plant of Acme Steel Co. for annealing strip steel both in nested coils and in flat, piled cut lengths; raw producer gas from mechanical producer brought to furnaces; arrangement for controlling gas flow through manifold and for providing uniform temperature; control located in front of furnace.

FORGING. Standard Units for Forging Furnaces. *Iron Age*, vol. 122, no. 3, July 19, 1928, pp. 149-150, 3 figs.

From a few sizes of bed, side and end plates, furnaces of varying internal dimensions may be quickly assembled at McCormick works of International Harvester Co.; gas burners used; two hearth widths and four depths; heights of furnace walls regulated to maintain certain ratio of gas consumption; burner design is adaptation of venturi inspirator principle; burner port is flat.

FORGING—GAS FIRING. Research Will Lead to Forging Developments, D. H. Haines. *Am. Gas Assn. Monthly*, vol. 10, no. 7, July 1928, pp. 411-414, 2 figs.

Brief sketch of gas research now in progress at University of Michigan; in forging, gas as fuel possessed two advantages over oil: (1) that it permitted a better atmospheric control and (2) somewhat easier control of temperatures; development of technique which would make burning of steel impossible; brief sketch indicates fashion in which this project has been undertaken.

HEAT TREATING. Solving a Problem With a Pot-Type Hardening Furnace, R. H. Archer. *Am. Mach.*, vol. 68, no. 4, July 26, 1928, pp. 149-150, 4 figs.

Constructional features of furnace that increases production and decreases amount of rejected work; it is used for hardening camshafts; work is suspended in liquid bath by revolving type fixture; methods of quenching.

HEAT TREATING, GAS-FIRED. Special Gas-Fired Furnace Built to Heat Treat Manganese Steel Castings, O. W. Anderson. *Iron Trade Rev.*, vol. 83, no. 4, July 26, 1928, pp. 197-199 and 245, 6 figs.

Important factors in heat-treating manganese-steel castings and how they are observed in specially built furnace; combustion confined to specially designed refractory combustion chamber so that volumes of air and gas are allowed to burn without dilution; hearth of car maintained at same temperature as upper portion of furnace; door automatically sealed.

INDUSTRIAL — MAINTENANCE AND REPAIR. Furnace Maintenance and Repairs, W. J. May. *Mech. World (Lond.)*, vol. 94, no. 2166, July 6, 1928, pp. 11-12, 1 fig.

In furnaces used for crucibles adherence of slag has to be considered; in cupolas and other furnaces working under blast, where possible, double lining should be put in; with some annealing furnaces very small change of some parts will alter operation of whole concern; no change should be made in entrances or exits used in distributing heated gases.

MELTING, CRUCIBLE. Crucible Melting Furnaces, A. J. Smith. *Metallurgist (Supp. to Engineer, Lond.)*, July 27, 1928, pp. 101-103, 4 figs.

Case against solid fuel; describes unusual

construction encountered in France, which is opening type, which does away with difficult and sometimes dangerous operation of withdrawing crucible of molten metal by tongs; describes also English design operated under forced draft furnished by small fan giving pressure of about 2½ in. water gage, air supply being preheated by passing between furnace lining and body.

HARDNESS TESTING MACHINES

Cloudburst Hardness Testing and Work-Hardening Machine. *Machy. (Lond.)*, vol. 32, no. 822, July 12, 1928, pp. 468-469, 5 figs.

Details of E. G. Herbert patent machine constructed by B. & S. Massey; main feature of machine is its ability to test rapidly and comprehensively large numbers of components in which minimum hardness is essential; machine rains down large number of hard steel balls on whole surface of component from height adjusted to requirements; addition to hardness testing, machine may be used for work hardening.

Universal Machine for Testing Cast Iron Hardness, Flexure and Shear, and Machine to Test Steel Metal for Stamping and Compression (Machiné universelle pour l'essai des fontes à la dureté, à la flexion statique et au cisaillement, et machine à essayer les métaux en feuilles à l'emboutissage et à la traction), R. Guillery. *Bul. de la Société d'Encouragement pour l'Industrie Nationale (Paris)*, vol. 127, no. 6, June 1928, pp. 483-502, 23 figs.

Describes machines for making tests on castings and sheet metal; Brinell process used for hardness tests.

Hardness Testing Machine. *Instruments*, vol. 1, no. 7, July 1928, pp. 335-336, 1 fig.

Description and method of using Johnson hardness testing machine; designed for rapid and accurate work; withstands rough shop use; requires practically no attention or adjustment; has no springs, knife edges, or multiple levers; all moving parts work on ball bearings.

Scratch Hardness Tester. *Instruments*, vol. 1, no. 7, July 1928, pp. 329-330, 1 fig.

Detailed description of the instrument consisting of scratch diamond and microscope either of which can be moved over table for test piece.

HIGH-SPEED STEEL

High Speed Steel, E. A. Brophy. *Chem. Eng. and Min. Rev. (Melbourne)*, vol. 20, no. 237, June 5, 1928, pp. 305-307.

Discussion of relative merits of crucible steel and electric-furnace products; author concludes that product of electric furnace is superior due to (1) control of temperature, (2) homogeneity of product, (3) mathematical precision of analysis, (4) constant repetition of specification, (5) absolute control of slag, oxidizing, neutral, and reducing.

CUTTING. Machinery Toughened Manganese Steel. *S. African Min. and Eng. Jl. (Johannesburg)*, vol. 39, no. 1913, May 26, 1928, p. 383, 2 figs.

Extols remarkable cutting capabilities of new high-speed tool steel; describes convincing demonstration and submits figures regarding S.O.B.V. alloy, introduced by Samuel Osborn and Co. of Sheffield.

IMPACT TESTING

Impact Tests of Steel (Essais de l'acier à la traction par choc), P. Régnauld. *Revue de Métallurgie (Paris)*, vol. 25, no. 5, May 1928, pp. 262-271, 13 figs.

Describes specimens used in testing, apparatus used and methods of testing on full and notched bars.

INGOT MOLDS

DESIGN. The Trend of Ingot Mold Design, R. H. Watson. *Blast Furnace and Steel Plant*, vol. 16, no. 6, June 1928, pp. 758-761, 4 figs.

June: Present tendencies in design based on carefully observed practice; life of molds secondary to steel quality; question of taper; value of and requirements for hot top; effect of wall thickness upon segregation and blowholes. July: Variations from straight-sided ingot; influence of shape of stool; mold life in comparison with resulting steel quality. Abstract of paper presented before Am. Iron and Steel Inst.

IRON

INCLUSIONS. Inclusions in Iron, C. R. Wohrman. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 255-299, 45 figs.

Photomicrographic study; sulphide inclusions; high-sulphur melts; medium and low sulphur melts; excess sulphur melts; iron-manganese-sulphur systems.

IRON AND STEEL

CORROSION, SEA WATER. Deterioration of Structural Iron and Steel in Sea Water. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3150, July 13, 1928, p. 43.

Summary of report of committee of Instn. Civil Engineers; specimens exposed for 5 years removed from sea at Halifax, Aukland, Colombo and Plymouth; bars still in position consist of series to be exposed for total periods of 10 and 15 years; description of bars and condition after 5 years of exposure; 36 per cent nickel steel L bars were only specimens at Aukland which bore no traces of rust; addition of small quantities of copper enhances resistance of steel to corrosion; experiments with protective coatings.

IRON AND STEEL INDUSTRY

Eliminating Waste in Distribution, C. M. Schwab. *Iron and Steel of Canada (Gardenvale, Que.)*, vol. 11, no. 7, pp. 206-207.

Outstanding facts of economic ills of steel industry; low margin of profit in steel industry is not conducive to sustained national prosperity; hunger for tonnage and desire to operate at capacity chief causes of cross hauling of steel products; committee of expert steel men proposed to study problem and recommend plan for eliminating waste in distribution. From address of President, Am. Iron and Steel Inst.

IRON CASTINGS

ELECTRIC WELDING. The Electric Cold Welding of Heavy Castings in Metallurgical Works (Die elektrische Kaltschweissung von schweren Gusstecken), H. Kochendoerffer. *Archiv fuer das Eisenhuettenwesen (Dusseldorf)*, vol. 1, no. 12, June 1928, pp. 781-784, 18 figs.

Description of armature welding with in-

sertion of forged-iron pieces, according to different methods; nature of electrode materials; gives various examples of applications.

GRAY. Way to Improve Gray Iron Castings, R. Moldenke. *Iron and Steel of Can. (Gardenvale, Que.)*, vol. 11, no. 8, Aug. 1928, pp. 240-242.

Most important advances made recently by scientists rather than men in active operation of foundries; iron melted under conditions of superheat, far beyond ranges of ordinary practice, may give castings perhaps twice as strong; superheated metal held before pouring; composition of high-test irons. Abstract of paper presented at European Foundrymen's Congress, Barcelona, Spain.

SHRINKAGE. Study of Shrinkage in an Iron Casting, M. Servais. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 620, July 5, 1928, pp. 9-10, 7 figs.

Author endeavors to examine process of shrinkage in gray iron casting and to determine whether cast iron is capable of elongation or contraction when hot; it would appear that judicious selection of method of pouring is necessary.

SHRINKAGE. Design and Shrinkage, F. C. Edwards. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 624, Aug. 2, 1928, pp. 75-76, 7 figs.

Author points out danger of overlooking or ignoring shrinkage stress; core irons in large cores; re-entrant angle; bending as preventive; uniformity of section desirable; amelioration by heat ducts; test bar castings.

IRON FOUNDRY PRACTICE

Which Should Apply—Theory or Practice?, J. Shaw. *Foundry*, vol. 56, nos. 13 and 14, July 1 and 14, 1928, pp. 519-522, 13 figs.

July 1: Manganese sulphide, evolution method for determining sulphur, effect of phosphorus, effect of melting temperature, and wide range of analyses covered by cast iron are discussed. July 15: Effect of size of test bar and number of reports of cast iron failures are taken up.

German Foundrymen Meet in Danzig, H. Hermanns. *Foundry*, vol. 56, no. 14, July 15, 1928, pp. 587-588, 1 fig.

Review of 1928 meeting of Association of German Iron Founders (Verein Deutscher Eisengiessereien) held in Danzig with brief abstract of papers; "Principles of Testing Molding Sands," M. Aulich; "Cast Iron with Improved Properties," M. Jungbluth; "Effect of Control of the Blast Furnace on the Properties of Pig Iron," M. Thaler; "Research on the Growth of Cast Iron," M. Jungbluth; "New Horizontal Cylindrical Melting Furnace for Cast Iron," M. Bardenheuer; and other papers.

IRON-NICKEL ALLOYS

ELECTRODEPOSITION. The Electro-Deposition of Iron-Nickel Alloys, S. Glasstone and T. E. Symes. *Faraday Soc.—Trans. (Lond.)*, vol. 24, no. 7, July 1928, pp. 370-378, 5 figs.

Paper contains results of experiments made with object of determining whether presence of certain anions or cations had any influence on composition of deposited alloy; preparation of electrolytes; discussion of results.

IRON-NICKEL-CHROMIUM ALLOYS

ELECTRIC PROPERTIES. Influence of Chromium Addition on the Electrical Properties of Iron-Nickel Alloys (Der Einfluss eines Chromzusatzes auf die elektrischen Eigenschaften der Eisen-Nickel-Legierungen), P. Chevenard. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 31, Aug. 2, 1928, pp. 1045-1049, 12 figs.

Account and results of investigations; influence of chromium on the electrical properties of nickel and of reversible iron-nickel alloys; results are in agreement with earlier investigations; new anomaly was established in field of paramagnetic state, termed Anomaly X.

IRON-SILICON ALLOYS

The Mechanical Properties of Iron-Silicon Alloys, T. Meierling and W. Denecke. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 620, July 5, 1928, p. 14, 2 figs.

Study of relationship between silicon contents and mechanical properties of iron-silicon alloys containing up to 20 per cent silicon. Abstract translated from Giess, Apr. 27, 1928.

LOCOMOTIVES

PARTS — FAILURES. Locomotive Part Failures and Their Microstructure, F. H. Williams. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 211-224, 15 figs.

Author reviews many types of failures and gives analysis of causes for failure in few specimens; points out need for closer inspection both of raw material and finished product in railroad maintenance and construction work; study of welded parts; analyzes use of acetylene torch in manufacture of locomotive parts; study of manufacture of locomotive frames; throughout paper author has discussed use of alloy steels; typical photomicrographs are included.

MAGNESIUM ALLOYS

HEAT CONDUCTIVITY. Thermal Conductivities of Some Light Alloys, H. J. Maybrey. *Metal Industry (Lond.)*, vol. 33, no. 1, July 6, 1928, pp. 5-6, 1 fig.

Magnesium-alloy investigations; outline of method employed in determining thermal conductivity figures, together with results; calibration against other metals.

MANGANESE STEEL

CASTING. Make Steel in a Converted Iron Foundry, F. B. Fletcher. *Foundry*, vol. 56, no. 14, July 15, 1928, pp. 572-575, 6 figs.

Conversion of gray iron foundry into plant for production largely of manganese and other alloy steel castings; new unit known as Plant D of American Manganese Steel Co.; steel melted in 1½-ton electric furnace; sand handling, cleaning room and molding machine equipment; 12 ovens in coreroom; 2 generators for oxyacetylene welding.

MATERIALS

X-RAY ANALYSIS. X-Ray Used in Identification of Crystalline Substances, A. N. Winchell, E. D. Johnson. *Rock Products*, vol. 31, no. 13, Aug. 18, 1928, pp. 63-65, 3 figs.

Advantages and disadvantages of improved method developed by A. W. Hull, using X-ray diffraction machine consisting of transformer

capable of supplying 1 kw. at approximately 30,000 v.; Coolidge tube, set of slits to limit beam, sheet to act as filter, small glass tube to hold powdered substance, and photographic film.

MATERIALS TESTING

UNITED STATES NAVY. Purchase on a Work Factor Basis, T. J. Keleher and F. M. McGeary. *Mfg. Industries*, vol. 16, no. 3, July 1928, pp. 193-196.

Standard tests for industrial supplies bought by United States Navy are applicable to items purchased by manufacturing plants; method of testing asbestos high pressure rod packings and foundry crucibles.

METALS

CLEANING. Practical Industrial Metal Cleaning. *Black and White*, vol. 1, no. 3, Mar. 1928, pp. 36-38.

Chief method of cleaning metal parts is by dipping them; tanks and methods of agitation; electric cleaner; airlines; metal washing machines; steam guns.

CLEANING. Practical Industrial Metal Cleaning. *Black and White*, vol. 1, no. 4, June 1928, pp. 28-30.

Correct use of materials; important points to check when trouble arises in cleaning department; strength of solutions; temperature; improper rinsing; troubles; precautions; additional causes of trouble which are sometimes overlooked.

COLD WORKED—ELASTICITY. On the Change of Elastic Constant in Metals Caused by Cold-Working, K. Honda and R. Yamada. *Tohoku Imperial Univ. Science Reports (Japan)*, vol. 17, no. 3, June 1928, pp. 723-742, 16 figs.

Change of Young's modulus of elasticity due to cold working was measured for iron, steel, copper, aluminum, and brass; method of experiment and materials used.

CORROSION. Corrosion Fatigue Discussed at A. S. T. M. Meeting. *Chem. and Met. Eng.*, vol. 35, no. 7, July 1928, p. 406.

Important discoveries concerning effect of corrosion and corrosion inhibitors on endurance of metals under repeated stresses were presented at summer meeting of Am. Soc. Testing Materials held in Atlantic City, June 25 to 29; paper by D. J. McAdams, and another by F. N. Speller and his associates, brought out most recent findings in field of corrosion-accelerated fatigue and lessening of such accelerated tendencies, respectively.

CORROSION. The Relative Corrodibilities of Ferrous and Nonferrous Metals and Alloys, J. N. Friend. *Engineering (Lond.)*, vol. 126, no. 3263, July 27, 1928, pp. 115-118, 12 figs.

Results of four years' exposure in Bristol Channel. Paper read Inst. of Metals, previously indexed.

CORROSION RESISTANCE — TESTING. Simple Apparatus for Determining the Corrosive Resistance of Alloys (Appareil simple pour la determination de la resistance aux corrosions des alliages), H. Thyssen and J. Bourdouxhe. *Revue Universelle des Mines (Liège)*, vol. 19, no. 2, July 15, 1928, pp. 63-67, 3 figs.

Describes apparatus used for making corrosive tests of metals by acid in a short time.

MOLTEN — HANDLING. Molten Iron Carried Ten Miles. *Sheet Metal Worker*, vol. 19, no. 13, June 29, 1928, pp. 422-423, 7 figs.

Armco formally inaugurates ten-mile transportation of hot metal from blast furnace to open-hearth furnace; one of remarkable features of this project is weight of cars used for carrying hot metal; length of about 56 ft. with four axles at each end, or 16 wheels in all; when loaded with molten iron they weigh total of 685,000 lb.; shows various interesting steps and processes involved in melting and handling of this iron from ore to open-hearth furnace.

HEAT TREATMENT. The Heat Treatment of Metals, E. Pull. *Machy. Market (Lond.)*, no. 1443, June 29, 1928, pp. 589-590.

Various methods of heat treatment and applications are described; theory of annealing; annealing castings; normalizing; annealing copper and alloy steels; hardening carbon steels; heating and cooling baths; hardening alloy steels; color tempering; case hardening; cyanide case-hardening.

SPECTRAL ANALYSIS. Use of Spectrum Analysis in Metallurgical Research (L'applicazione dell' analisi spettrale alle ricerche metallurgiche), R. Volterra. *Giornale di Chimica Industriale ed Applicata (Milan, Italy)*, vol. 10, no. 6, June 1928, pp. 313-318, 3 figs.

Principles of spectrum analysis of metals, qualitative analyses and possibilities of quantitative spectrographic analyses; description of equipment and research work of spectrographic laboratory of Ernesto Breda Institute at Sesto San Giovani; international bibliographic list of 14 references on spectrography.

TESTING. Testing Society Meets. *Foundry*, vol. 56, no. 14, July 15, 1928, pp. 563-568.

Review of annual meeting of Am. Soc. for Testing Matls. with abstract of papers; many properties of cast metals given; cast iron given intensive study; specifications for nonferrous metal; methods to check wear resistance of metals; new data on cast steel presented. See also Metal Industry (N. Y.), vol. 26, no. 7, July 1928, pp. 311-312.

METALS CUTTING

TEMPERATURE EFFECTS. Cutting Tools Research Committee Report on Cutting Temperatures: Their Effect on Tools and on Materials Subjected to Work, E. G. Herbert. *Instn. Mech. Engrs.—Proc. (Lond.)*, no. 4, 1927, pp. 863-892 and (discussion) 893-908, 21 figs.

Heat-resisting properties of high speed steel after subjection to primary and secondary hardening temperatures; hot hardness as means of determining predominant factor in tool efficiency; effect of cutting temperatures on work; steel and many other metals show marked decline in their capacity to work harden when within free cutting range; research towards finding source of work hardening changes in metals.

METALLOGRAPHY

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt and M. V.

Schwarz. *Iron Trade Rev.*, vol. 83, no. 6, Aug. 9, 1928, pp. 324-325, 5 figs.

Further study of steel etched macroscopically; it is absolutely essential to determine position of segregated zone clearly by etching or sulphur print test before sample for analysis is taken; segregation in boiler plate which should be rejected is shown; brittleness caused by segregation is especially dangerous in boiler plates.

MICROGRAPHS

The Ransden Reflex Micrograph. *Engineering (Lond.)*, vol. 126, no. 3261, July 13, 1928, pp. 42-44, 5 figs. on p. 46.

Details of instrument designed by J. V. Ramsden; although all classes of work that can be carried out with ordinary microscope can be done at least as well with Ramsden micrograph, latter is designed more on lines of precision tool than scientific instrument; it can be supplied for examination of either transparent or opaque objects and in simplified form for rapid routine inspection of either class of objects.

MOLYBDENUM STEEL

Molybdenum Steels, F. W. Rowe. *Iron and Steel Industry (Lond.)*, vol. 1, no. 11, Aug. 1928, pp. 339-341.

Composition, properties, and engineering applications of molybdenum steels are described.

NICKEL ALLOYS

PROPERTIES. Nickel, An Account of Its Alloys and Its Uses, A. C. Sturney. *Min. Mag. (Lond.)*, vol. 38, no. 6, June 1928, pp. 341-347.

Properties of nickel; commercially pure metal is generally brittle and non-malleable; small percentage magnesium renders it ductile, malleable, and amenable to fabrication, soldering, and welding by arc or acetylene; uses enumerated; nickel steels; ferronickel alloys of low thermal expansion, and of high magnetic permeability; nonmagnetic nickel iron; nickel cast iron; nickel-copper alloys; nickel-brass, bronze and aluminum bronze; heat-resistance alloys; nickel in aluminum.

NONFERROUS METALS

ANTI-CORROSIVE. Resistance to Corrosion. Use of Nonferrous Metals, H. J. French. *Indus. Australian and Min. Standard (Melbourne)*, vol. 79, no. 2048, June 14, 1928, p. 564.

Uses of aluminum, lead, and tin, and their alloys from standpoint of resistance to corrosion; many factors influence resistance; cost of metal may be prohibitive or physical properties such as to make application difficult; lead not adapted to structural work; high-silicon irons are brittle; wrought metals frequently superior to corresponding alloys in cast condition. Abstract of paper presented before Am. Electrochem. Soc.

OIL BURNERS

DESIGN. The Trend of Oil Burner Design, C. H. Chalmers. *Domestic Eng. (Chicago)*, vol. 124, no. 2, July 14, 1928, pp. 45 and 47, 2 figs.

Progress in matter of oil-burner design rests upon two foundations; one of these is experience gained in field; other is that of scientific research in laboratory; three periods of oil-burner research; oil burners that are simple, efficient and beautiful.

OPEN-HEARTH FURNACES

CARBURIZING MEDIA. The Addition of Carburizing Media in Open-Hearth Furnaces Heated with Mixed Gas (Zusatz von Karburierungsmitteln bei mit Mischgas beheizten Siemens-Martin-Oefen), F. Stein. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 27, July 5, 1928, pp. 907-908.

Abstract of report published in Archiv fuer das Eisenhuettenwesen, Apr. 1928, previously annotated.

DESIGN. The Flow of Heat Through Furnace Hearths, J. D. Keller. *Fuels and Steam Power (A. S. M. E. Trans.)*, vol. 50, no. 15, May-Aug. 1928, pp. 111-121 and (discussion) 121-124, 21 figs.

Author points out lack of definite knowledge upon which engineer can base calculations of heat losses through furnace hearths; solid or non-ventilated type of hearth is discussed, and certain conclusions as to relations of heat flow to shape and construction are reached; greater part of paper is devoted to explanation of methods used in arriving at these conclusions; formulas and examples illustrating their use are given for each of several types of hearths discussed.

INSULATION. Effect of Insulation on Open-Hearth Furnaces and Soaking Pits, W. T. Kennedy. *Blast Furance and Steel Plant*, vol. 16, no. 7, July 1928, p. 952, 1 fig.

Discussion of results obtained through insulating open-hearth furnaces and soaking pits; no indication that insulation has any effect upon life of refractories; comparison of insulated and uninsulated chamber walls.

PRESSURE LOSSES. Measurement and Calculation of Pressure Losses, Especially in Open-Hearth Furnaces (Messung und Errechnung der Druckverluste insbesondre in Siemens-Martin-Oefen), W. Neil. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 1, no. 12, June 1928, pp. 729-740, 10 figs.

Note on resistance occurring in furnaces; pressure losses in pipe lines and in different sections of open-hearth furnaces; critical discussion of experimental results; comparison of results of measurements and calculations and conclusions therefrom. Bibliography.

PHOTOELASTICITY

RESEARCH. Photoelastic Research (Spannungsoptische Untersuchungen von ebenen Spannungszustaenden). *V.D.I. Zeit. (Berlin)*, vol. 72, no. 27, July 7, 1928, pp. 951-959, 41 figs.

Application of photoelastic methods to engineering problems; study of strain deformations in chain links; thick cylinder walls; test specimens in tension and shear; concrete testing, study of elastic deformations in cutting metals.

PHOTOMICROGRAPHY

Photomicrography in Natural Color, T. S. Curtis. *Am. Ceramic Soc.—Jl.*, vol. 11, no. 8, Aug. 1928, pp. 609-632, 7 figs.

Outline of processes and technique used in Vitrefrax Laboratory for preparation of permanent and faithful records of ceramic and refractory body structures.

PICKLING (METALS)

The Theory and Practice of Pickling. *Wire*, vol. 3, no. 7, July 1928, pp. 229-230.

Properties of acid solutions of various strengths, effects of temperature control and uses of inhibitors; kinds of scale; kinds of acid; acid strength and temperature; pitting; acid brittleness; formation of iron salts.

PYROMETERS

RADIATION. K & S Pocket Radiation Pyrometer. *Instruments*, vol. 1, no. 7, July 1928, pp. 333-334, 2 figs.

Description of instrument of total radiation type; fundamental principle upon which it operates is measurement of total radiant energy emitted by hot body.

RAILROADS

TIES, STEEL. Note on Steel Sleeper Design, F. S. Hughes. *Government of India Central Publication Branch (Calcutta),—Tech.*, paper no. 260, 1928, 17 pp., 5 supp. plates.

Two reasons which determined use of steel ties for this work; design of steel tie strong enough to stand up to these loads has been carefully considered and close theoretical investigations have been made; memorandum of test of steel tie carried out at Government Test House, Alipore.

RAILS

CHROMIUM-STEEL. Properties of Chromium Steel Rails, T. Swinden and P. H. Johnson. *Heat Treating and Forging*, vol. 14, no. 7, July 1928, pp. 764-768, 4 figs.

Gradual development of steel rails of greater and greater hardness is briefly noted and advisability of relying essentially on increase in carbon content for this purpose is questioned; results and permanent-way experience of quantity of chromium steel rails are quoted showing that there is every prospect of useful future for such material where heavy duty is encountered. Paper presented before Brit. Iron and Steel Inst.

HEAVY. Heavier Rails for Heavy Traffic. *Ry. Age*, (2nd. sec.), vol. 85, no. 5, Aug. 4, 1928, pp. 209-212, 3 figs.

Locomotive design to ease stresses in rails; recent developments in use of heavier rails to ascertain practice of various roads in United States and Canada with respect to present weight of rails for heavy traffic lines and probable future trend; questionnaire was addressed to chief engineers of these roads; information contained in replies; reasons for heavier rails.

TRANSVERSE FISSURES. Surface Fissures in Rail Treads, Viteaux. *Metallurgist (Supp. to Engineer, Lond.)*, July 27, 1928, pp. 99-101.

Description of test in which test tracks were laid down with carefully selected and tested rails; comparison of behavior of soft with harder basic rails both in normal state and after heat treatment; effect of heavier engine, behavior of Siemens-Martin steels and effect of wear of treads of heat treated rails, were studied; principal remedial measures urged are avoidance of all circumstances favoring cold working or auto-quenching and use of heat treated rails.

STEEL. Increasing Rail and Tire Life, J. Silberstein. *Elec. Ry. Jl.*, vol. 72, no. 4, July 28, 1928, p. 138.

It should be possible to get greater wear by suiting rail and wheel surfaces to each other; natural tendency toward use of harder steels has been followed extensively in practice; at present tire is much harder than rail and rail is worn away.

The Steel Rail—Reliability Versus Wearing Capacity. *Ry. Engr. (Lond.)*, vol. 49, no. 583, Aug. 1928, pp. 306-307.

Some notes by correspondent on steel rails, with especial reference to analysis and physical tests required under British Standard Specification; high standard of track equipment; wearing capacity of rails; B. S. S. requirements.

HEAT TREATMENT. Improvement of Rail Steel (Wege zur Verbesserung des Schienenbaustoffes), H. Viteaux. *Stahl u. Eizen (Duesseldorf)*, vol. 48, no. 28, July 12, 1928, pp. 940-945, 11 figs.

Author refers to article by O. Pilz, published in same journal, 1927, p. 1645, in which he deals with different methods of heat treatment of rails and increase of wear resistance; present author points to great improvement in resistance against widening of cracks, which has been accomplished by heat treatment at Neuves-Maison. Includes reply by Pilz.

WEIGHT INCREASE. Catching Up With the Locomotives. *Ry. Eng. and Maintenance*, vol. 24, no. 8, Aug. 1928, pp. 328-335, 4 figs.

Race between axle loadings and weight of rails carrying those loads; locomotive design to ease stresses in rails; rails are designed for greater girder strength; advance in weight of rails in 1916; recent developments in use of heavier rails; reasons for heavier rails; probable trend in weight of rails; specific benefits from heavier sections; fewer rail failures; longer life demonstrated; further improvements desired; Am. Ry. Eng. Soc. specifications are widely used; use of intermediate manganese steel.

REFRACTORY MATERIALS

Notes on Composition, Use, and Manufacture of Certain Refractory Materials and Products (Notes sur les compositions, usages, modes de faconnage, de certains matériaux et produits refractaires, argileux et siliceux), P. Renault. *Revue des Matériaux de Construction et de Travaux Publics (Paris)*, no. 225, June 1928, pp. 137B-141B, 10 figs.

Treats of accessories to firing of hard porcelain and different ceramic products of similar manufacture; does not deal with glazing materials.

ROAD MATERIALS

ANALYSIS. Chemistry in Road Building (Chemie im Strassenbau), Skopnik. *Chemiker-Zeitung (Koethen)*, vol. 52, no. 40, May 19, 1928, pp. 397-398.

Road construction laboratory of Province of Brandenburg has worked out analysis process which is stated to give results of as exact nature as possible; results of investigations made by process are given. See translated abstract in Quarry and Surveyors and Contractors Jl. (Lond.), vol. 33, no. 377, July 1928, pp. 262-263.

ROLLING MILL PRACTICE

Investigation and Inspection of Rolling Mills (Untersuchung und Ueberwachungsverfahren der Walzwerke), G. Bulle. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 1, July 1928, pp. 11-18, 18 figs.

Notes on selection of suitable plant; experiments in rolling mills including investigation of product and compilation of results on record sheets; influence of rolling process on quality of product; furnace tests, including fuel consumption and combustion; instruction by means of lectures on design, operation, and drive of rolling mills, furnace construction and operation, and measuring instruments.

ROLLING MILLS

Passes for Hot-Metal Rolling, H. A. Slattengren. *Iron Age*, vol. 122, no. 3, July 19, 1928, pp. 146-147.

Shapes and sizes of various grooves making up passes used in hot rolling are calculated, and relation they bear to each other discussed; temperature of ingot or billet is main point considered in designing grooves; comparative plasticity of metals at rolling temperatures determines relative sizes of passes.

DIAGONAL. Investigations of Power Consumption in Diagonal Rolling Mills in Regard to Economy (Untersuchungen ueber den Kraftverbrauch beim Schraegwalzen bei Beruecksichtigung der Wirtschaftlichkeit), W. Moritz. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 1, no. 12, June 1928, pp. 741-753, 38 figs.

Author discusses relation of power consumption to various conditions; economic considerations.

ELECTRIC DRIVE. Driving of Irreversible Rolling Mills by 3-Phase Motors (La commande deslaminoirs irréversibles par moteurs à courant triphasé). *Génie Civil (Paris)*, vol. 92, no. 25, June 23, 1928, pp. 613-616, 7 figs.

Treats of single speed mills, rolls with flywheels, variable speed mills, and various arrangements of motors and examples of application.

SHEET MILLS

ELECTRIC DRIVE. Electric Control Enables Continuous Sheet Rolling, T. J. Flaherty and A. F. Kenyon. *Elec. World*, vol. 92, no. 3, July 21, 1928, pp. 103-107, 7 figs.

Electrification of Ashland, Ky., plant of American Rolling Mill increases output per workman, reduces hand labor, and maintains high standard of product.

SHEET STEEL

HEAT TREATMENT. Effect of Heat Treatment on the Properties of Chromium-Molybdenum Sheet Steel, F. T. Sisco and D. M. Warner. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 2, Aug. 1928, pp. 177-192, 18 figs.

Test results on chromium-molybdenum sheet of composition suitable for use in aircraft construction; effects of heat treatment on physical properties and structure are shown for sheet of several gages; for best combination of strength and ductility sheet should be normalized, hardened by quenching in water from 1600 deg. Fahr., and tempered between 1000 and 1200 deg. Fahr.; elongation after heat treatment decreases materially as gage becomes thinner.

TESTING. Properties and Tests of Sheet Steel for Stampings (Pruefung und Eigenschaften von Feinblechen fuer Stanzzwecke), W. Aumann. *Maschinenbau (Berlin)*, vol. 7, no. 14, July 19, 1928, pp. 669-675, 20 figs.

Report from testing materials laboratory of Siemens-Schuckert A.-G., on effect of method of rolling on hardness and other properties of sheet steel; meaning of Erichsen cupping test; cupping depth-hardness tables for sheets of steel, brass, copper, aluminum, etc.; effect of metal texture on ball hardness.

STAINLESS STEEL

Stainless Steels Have Many Uses in Protection Against Corrosion, J. C. C. Holding. *Iron Trade Rev.*, vol. 83, no. 7, Aug. 16, 1928, pp. 379-381.

History, physical properties, and applications of stainless iron and steels are given; consumption of these materials has increased 600 per cent in last three years; stainless cutlery steel forged by methods applied to high speed steel; high physical properties of stainless iron at elevated temperatures; precautions in welding and machining. From paper presented before Am. Soc. Steel Treating.

APPLICATION. Progress of Stainless Steel. *Times Trade and Eng. Supp. (Lond.)*, vol. 22, no. 526, Aug. 4, 1928, p. 520.

Review of progress; great chain made by Brown Bayley's Steel Works for binding dome of St. Paul's cathedral, weight 80 tons, is 450 ft. long, and largest of its kind ever made; result of six weeks' test on stainless steel plate made on liner Arandora to determine action of sea air and salt water.

WELDING. Welding of Stainless Steel. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3147, June 22, 1928, p. 941.

Brief note states that Alloy Welding Processes, Ltd., succeeded in satisfactorily welding stainless steel nearly 7 years ago; have been supplying about 18 different types of stainless steel electrodes; claim that it is only during past 18 months or 2 years that welding of such steels has been accomplished in United States and then only by use of materials imported from England.

WELDING. Welding Stainless Steels, J. B. Green. *Welding Engr.*, vol. 13, no. 7, July 1928, pp. 40-43, 4 figs.

Selection of parent metals, welding and cutting process, from standpoint of cost in commercial application; author recommends that all who consider making welded articles of rolled stainless-steel plates, sheet bars, etc., for first time, consider only what is known as air quenching alloy; consideration of fusion process; real basis of choice goes back to cost of repeated experiment and failure.

X-RAY ANALYSIS. Discussion of Paper by E. C. Bain entitled X-Rays and Constituents of Stainless Steel, J. Strauss. *Am. Soc.*

Steel Treating—Trans., vol. 14, no. 2, Aug. 1928, pp. 316-317.

It is believed that had author carried his tests to higher tempering temperatures maximum values of corrosion for higher quenching temperatures would have been secured in vicinity of 1110 deg. Fahr.; includes Bain's reply.

STEEL

ABRASION. An Investigation of Abrasion in Carbon Steels, M. Suzuki. *Tohoku Imperial Univ.—Science Reports (Japan)*, vol. 17, no. 3, June 1928, pp. 573-638, 67 figs. partly on supp. plates.

Writer has extensively measured relative abrasion for six hypoeutectoid carbon steels with apparatus devised by him; measurement always made under constant coefficient of friction; two important laws for relative abrasions of different steels.

AUTOMOBILE. British and American Automotive Steels, J. W. Urquhart. *Blast Furnace and Steel Plant*, vol. 16, no. 7, July 1928, pp. 906-908.

Features of difference in steels exist in chemical specifications, resulting in less difficult heat treatments on parts in American practice; Ford Methods particularly are cited; complete dependence by Ford organization upon carbon steels which bear large percentage of manganese and chromium; depth of hardening in automobile work.

COLD DRAWING. Contribution to Study of Cold Drawing of Soft Steel (Contribution à l'étude de l'étirage à froid de l'acier doux), R. Giraud. *Revue de Métallurgie (Paris)*, vol. 25, no. 5, May 1928, pp. 235-246, 4 figs.

Measurement of force necessary for drawing and mode of operation; influence of speed and reduction of section and number of passes.

CRUCIBLE—PROGRESS. Progress in the Production of Crucible Steels. *Iron and Steel Industry (Lond.)*, vol. 1, no. 11, Aug. 1928, pp. 335-336.

Progress in crucible steel production is discussed with description of results obtained by Ajax Northrup high frequency induction furnace; table of comparison of gas furnace-melted and high frequency-melted high speed steel; actual tests done at Sheffield Testing Works on same day and on same bar.

DEVELOPMENTS. Trend of Engineering Developments in Steel, B. D. Saklatwalla. *Chem. and Industry (Lond.)*, vol. 47, nos. 28 and 30, July 13 and 27, 1928, pp. 198T-202T and 210T-212T, 1 fig.

Factor of importance has been progress in art and science of heat treatment of steel; development of alloy steels is undoubtedly responsible for present-day engineering advances; engineering properties are dependent on structural constituents rather than on chemical composition of steel.

HEAT TREATMENT. Heat Treatment of Steel, H. M. Boylston. *Black and White*, vol. 1, no. 4, June 1928, pp. 7-14, 18 figs.

General facts and principles; definitions quoted are now accepted as tentative standards; rate of heating; simple heat treatment steps; definition of annealing; critical range; microstructure of steel; types of annealing; normalizing; spheroidizing; tempering; malleablizing; hardening; toughening treatments.

HEAT TREATMENT — DEFORMATION. Deformation of Case Hardened and Tempered Parts Due to Tempering (Deformations dues à la trempe dans les pieces céméntées et trempées), R. Barat. *Arts et Metiers (Paris)*, vol. 81, no. 94, July 1928, pp. 263-266, 9 figs.

Discusses changes in case hardened pieces due to tempering process after hardening; certain forms of parts tending towards deformation are explained and calculations made.

HEAT TREATMENT, ELECTRIC. Heat Treatment of Steel in the Electric Furnace. *Iron and Steel Industry (Lond.)*, vol. 1, no. 11, Aug. 1928, pp. 354-356, 2 figs.

Description of scientific heat treatment of steel; box, rotary, and continuous furnaces are outlined; comparison with coal-fired furnaces; results obtained with standard furnace made by Electric Furnace Co., London.

HEAT TREATMENT — PERMANENCE. Permanence of Heat Treatment of Steel—The Eads Bridge Arch Ribs, E. E. Thum. *Eng. News-Rec.*, vol. 101, no. 6, Aug. 9, 1928, p. 220.

Letter to editor presenting arguments against contention that effects of heat treatment of steel are not permanent.

HEAT TREATMENT — QUENCHING. Quenching in Hot Salt Baths Recommended. *Iron Age*, vol. 122, no. 4, July 26, 1928, p. 210.

Results of test by K. Honda and K. Tamaru; Swedish steel (0.89 per cent carbon) heated 15 min. at 800 deg. Cent., then quenched in mercury or salt baths at various elevated temperatures; it was found that sorbitic structures can be obtained by quenching in melted salt at about 500 deg. Cent. and give physical properties not inferior to those after water quenching and tempering; simpler method of heat treatment and avoids danger of quenching cracks.

MAGNETIZATION. Effect of Methods of Demagnetization on the Energy Required to Magnetize Steel, J. D. Ball. *Franklin Inst.—Jl.*, vol. 206, no. 2, Aug. 1928, pp. 181-200, 6 figs.

First series of tests consisted of obtaining zero flux in two varieties of steel from various maximum flux values and by three different methods; second series of tests consisted of taking set of hysteresis loops and repeating determinations, using greater number of steps, to find if by taking greater number of steps there might be greater indicated energy loss.

NITRIDE HARDENED — CORROSION RESISTANCE. Research on Corrosion of Nitride Hardened Steel (Untersuchungen ueber die chemische Angreifbarkeit nach dem Nitrierhaerteverfahren behandelter Sonderstaehle), O. Hengstenberg. *Kruppsche Monatshefte (Essen)*, vol. 9, June-July 1928, pp. 93-96, 3 figs.

Great corrosion-resisting properties of nitrogen-hardened steel compared to case hardened steel; steel surfaces resist precipitation of copper from copper sulphate solution; this is simple means to establish extent of nitride protective coating.

News of the Society

NATIONAL METAL EXPOSITION AND CONVENTION

THE celebration of America's Second National Metal Week will be held in Philadephia, October 8 to 12 inclusive. This week, dedicated to the gigantic metals industry, was chosen to coincide with the annual conventions of the American Society for Steel Treating, the American Welding Society and the Institute of Metals Divisions of the American Institute of Mining and Metallurgical Engineers at Philadelphia and the National Metal Exposition held in the Commercial Museum.

The outline of events for this week, incorporating the activities of these three national societies, is of such great interest and value that it will bring to Philadelphia an assemblage of 25,000 or more men vitally interested in the metals industry.

National Metal Week was first observed last year at the time of the same conventions and the National Metal Exposition in Detroit. Dedication of a week to an industry which involves more than five and a half billion dollars annually met with the hearty approval of leaders in the industry. It will find assembled in Philadelphia the world's leaders in the various branches of the metal field, convened there for the exchange of beneficial ideas and to get reports on development and progress of the past year.

Each year many new ideas are developed and new equipment produced that really are milestones in the progress of metals. The great minds of the industry are ever working toward perfection and annually the great industry is aided immensely by these new products.

Especially important are the developments made in the welding field and 10,000 square feet of space at the exposition has been set aside for a special exhibit of welding and cutting equipment and supplies with demonstrations of the equipment. The exposition will occupy the entire capacity of 80,000 square feet in Commercial Museum.

Greater attention than ever before is to be given the airplane at the annual convention and exposition of the American Society for Steel Treating. Much study has been given the construction of airplanes and scientists are doing everything possible to eliminate defects which in the past have been responsible for air tragedies.

In observance of National Metal Week, three societies will hold technical sessions at Philadelphia at which will be read many papers showing the advancement made in the past year. Thousands of engineers, executives and others directly interested in the metals industry will be in attendance.

Tenth Annual Convention

The technical sessions of the Tenth Annual Convention of the American Society for Steel Treating maintain the usual high standard and forty-one

papers will be presented, covering subjects of vital importance to the industry and setting forth new ideas and adaptations. These papers have been prepared and will be presented by recognized thinking men of the metal world. Worthwhile comment and discussion will follow the presentation of these papers and the members of the society and their guests will find valuable information awaiting them at these sessions. The morning sessions will be held in the ballroom of the Benjamin Franklin Hotel, and the afternoon sessions in the assembly room of the Commercial Musuem.

Campbell Memorial Lecture

The Edward DeMille Campbell Memorial Lecture will be presented by Dr. W. H. Hatfield, of Sheffield, England, on Wednesday morning, October 10, immediately following the close of the annual meeting of the American Society for Steel Treating. Dr. Hatfield, who is the director of the Brown-Firth Research Laboratories and whose reputation as a scientist and metallurgist is world-wide, will present a lecture of outstanding interest. Dr. George K. Burgess, director of the United States Bureau of Standards, will preside as chairman of the memorial session.

Annual Banquet of the American Society for Steel Treating

The annual banquet will be held at the Benjamin Franklin Hotel on Thursday evening, October 11th, at 6:30 P. M. Aviation will be the keynote of the evening and interestingly worth-while speakers will be present. All seats are reserved. Tickets at $5.00 each may be secured either by addressing the society headquarters in Cleveland or at the registration desk in Philadelphia.

Hotel Headquarters

The headquarters of the American Society for Steel Treating and of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers will be maintained at the Benjamin Franklin Hotel, with the Americal Welding Society holding sway at the Bellevue-Stratford Hotel.

Registration of members in attendance at the convention and exposition will be as follows:

A. W. S. registration—Bellevue-Stratford Hotel.
I. of M. registration—Benjamin Franklin Hotel.
A.S.S.T. registration (ladies only) Benjamin Franklin Hotel, Lafayette Room.
A.S.S.T. registration of members, guests and exhibitors—Commercial Museum.

Plant Inspection

Plant inspection trips have been arranged for Tuesday, Wednesday, Thursday and Friday mornings. Directional routings will be supplied from the Benjamin Franklin Hotel and the inspection tours through the various plants will start at 9:30 A. M. at each plant. Trips, as listed below, are open to all members and guests in attendance at the convention. Additional plant inspection trips have been arranged by the American Welding Society.

TECHNICAL PAPERS PROGRAM, TENTH ANNUAL CONVENTION AMERICAN SOCIETY FOR STEEL TREATING

PHILADELPHIA, OCTOBER 8-12, 1928

MONDAY, OCTOBER 8

Morning Session

Meeting in Ball Room, Benjamin Franklin Hotel

R. M. Bird, Chairman—Introduction

R. H. Patch, Vice-Chairman—Technical Session.

10:00—10:30 A. M.—*An Investigation of the Physical Properties of Certain Chromium-Aluminum Steels*—Frank B. Lounsberry and Walter R. Breeler, Atlas Steel Corporation, Dunkirk, N. Y.

10:30—11:00 A. M.—*Chromium-Copper Steels as Possible Corrosion Resisting Ferrous Alloys*—B. D. Saklatwalla and Albert W. Demmler, Vanadium Corporation of America, Bridgeville, Pa.

11:00—11:30 A. M.—*A New Development in Corrosion-Resisting Steel*—Frank R. Palmer, Carpenter Steel Co., Reading, Pa.

11:30—12:00 A. M.—*Stainless Iron and its Application to the Manufacture and Transportation of Nitric Acid*—Walter M. Mitchell, Central Alloy Steel Corp., Massillon, Ohio.

MONDAY, OCTOBER 8

Afternoon Session

Meeting in Assembly Room, Commercial Museum

A. E. White, Chairman

V. C. Homerberg, Vice-Chairman

2:30—3:00 P. M.—*Surface Hardening of Special Steels with Ammonia Gas Under Pressure*—Raymond H. Hobrock, Engineering Experiment Station, Purdue University, Lafayette, Ind.

3:00—3:30 P. M.—*Methods of Approximating Certain Physical Characteristics of Nitrided Steel Cases*—G. M. Eaton, Molybdenum Corp. of America, Pittsburgh.

3:30—4:00 P. M.—*Depth and Character of Case Induced by Mixtures of Ferro-Alloys with Carburizing Compounds*—E. G. Mahin, University of Notre Dame, Notre Dame, Ind., and R. C. Spencer, Caterpillar Tractor Co., Moline, Ill.

4:00—4:30 P. M.—*Solubility of Carbon in Normal and Abnormal Steels*—Oscar E. Harder, University of Minnesota, Minneapolis, Minn., and Willard S. Johnson, American Rolling Mill Co., Middletown, Ohio.

TUESDAY, OCTOBER 9

Morning Session

Meeting in Ball Room, Benjamin Franklin Hotel

J. A. Mathews, Chairman

M. A. Grossmann, Vice-Chairman

10:00—10:30 A. M.—*The Equation of the Carbon-Time Curve in Basic Open-Hearth Refining and Prediction of Carbon Drop*—

Alexander L. Feild, Union Carbide and Carbon Research Laboratories, Inc., New York City.

10:30—11:00 A. M.—*A Melting Record of Three Acid Open-Hearth Heats*—W. E. Griffiths, Union Carbide and Carbon Research Laboratories, Inc., Long Island City and C. E. Meissner, Chrome Steel Works, Carteret, N. J.

11:00—11:30 A. M.—*Manufacture of Acid Open-Hearth Steel for Forging Ingots*—H. P. Rassbach, Midvale Company, Nicetown, Philadelphia.

11:30—12:00 A. M.—*Deoxidation of Steel with Silicon*—Dr. C. H. Herty, Jr., and G. R. Fitterer, United States Bureau of Mines, Pittsburgh.

TUESDAY, OCTOBER 9

Afternoon Session

Meeting in Assembly Room, Commercial Museum

T. D. Lynch, Chairman
E. C. Bain, Vice-Chairman

2:30—3:00 P. M.—*Graphitization in the Presence of Nickel*—H. A. Schwartz, National Malleable and Steel Castings Co., Cleveland.

3:00—3:30 P. M.—*Influence of Nickel on Combined Carbon in Gray Iron*—J. R. Houston, The Harnischfeger Corp., Milwaukee.

3:30—4:00 P. M.—*Some Characteristics of Pearlite in Eutectoid Rail Steels*—O. V. Greene, Reading Company, Reading, Pa.

4:00—4:30 P. M.—*Cutting Qualities of an Alloy Steel as Influenced by its Heat Treatment*—O. W. Boston, University of Michigan, Ann Arbor, Mich., and M. N. Landis, Landis and Landis, Chicago.

WEDNESDAY, OCTOBER 10

Morning Session

Meeting in Ball Room, Benjamin Franklin Hotel

9:30—10:30 A. M.—*Annual Meeting of the American Society for Steel Treating*, President F. G. Hughes, Chairman.

10:30— A. M.—*Campbell Memorial Lecture* by Dr. W. H. Hatfield, Sheffield, England. Dr. G. K. Burgess, Chairman.
The Application of Science to the Steel Industry.

WEDNESDAY, OCTOBER 10

Afternoon Session

Meeting in Assembly Room, Commercial Museum

Dr. Zay Jeffries, Chairman
Charles McKnight, Vice-Chairman

2:30—3:00 P. M.—*Notes on Smoothing and Etching*—H. B. Pulsifer, The Beryllium Corp. of America, Cleveland.

3:00—3:30 P. M.—*Further Observations on the Microstructure of Martensite*—Francis F. Lucas, Bell Telephone Laboratories, New York City.

3:30—4:00 P. M.—*Treatment and Structure of Magnesium Alloys*—John A. Gann, Dow Chemical Co., Midland, Mich.

4:00—4:30 P. M.—*Neumann Bands in Ferrite*—C. H. Mathewson, Professor of Metallurgy, Yale University, New Haven, Conn.

4:30—5:00 P. M.—*A Study of the Constitution of High Manganese Steels*—V. N. Krivobok, Carnegie Institute of Technology, Pittsburgh.

THURSDAY, OCTOBER 11

Morning Session

Meeting in Ball Room, Benjamin Franklin Hotel

Albert Sauveur, Chairman
J. P. Gill, Vice-Chairman

10:00—10:30 A. M.—*On Oxygen Dissolved in Steel and its Influence on the Structure*—M. A. Grossmann, Central Alloy Steel Corp., Canton, Ohio.

10:30—11:00 A. M.—*Surface Cooling of Steels in Quenching*—H. J. French, G. S. Cook and T. E. Hamill, Bureau of Standards, Washington, D. C.

11:00—11:30 A. M.—*Tungsten Carbide, a New Tool Material*—S. L. Hoyt, General Electric Co., Schenectady, N. Y.

11:30—12:00 A. M.—*Austenite Decomposition and Length Changes in Steel*—Edgar C. Bain, U. S. Steel Corp., Kearney, N. J., and Willis S. N. Waring, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

On the Nature of Martensite Crystals—Dr. Kotaro Honda, Tohoku Imperial University, Sendai, Japan. (By Title)

THURSDAY, OCTOBER 11

Afternoon Session

Meeting in Assembly Room, Commercial Museum

J. Fletcher Harper, Chairman
Francis H. Clark, Vice-Chairman

2:30—3:00 P. M.—*Torsional Modulus of Carbon Steel, Phosphor Bronze, Brass and Monel Metal*—William P. Wood, University of Michigan, Ann Arbor, Mich.

3:00—3:30 P. M.—*Silicon-Manganese Steels with Chromium Additions for Engineering Applications*—A. B. Kinzel, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

3:30—4:00 P. M.—*Evaluation of the Stability of Metals at Elevated Temperatures from Expansion and Short-Time Tensile Test Data*—Albert E. White and Claude L. Clark, University of Michigan, Ann Arbor, Mich.

4:00—4:30 P. M.—*Cloudburst Process for Hardness Testing and Hardening*—Edward G. Herbert, Edward G. Herbert, Ltd., Manchester, England.

FRIDAY, OCTOBER 12

Morning Session

Meeting in Ball Room, Benjamin Franklin Hotel

Bradley Stoughton, Chairman
E. F. Cone, Vice-Chairman

10:00—10:30 A. M.—*Metallurgical Problems of Transmission Gearing*—Ernest F. Davis, Warner Gear Company, Muncie, Ind.

10:30—11:00 A. M.—*Decarburization of High Carbon Steel in Reducing Atmospheres*—J. J. Curran and J. H. G. Williams, Henry Souther Engineering Co., Hartford, Conn.

11:00—11:25 A. M.—*Service Annealing of Sling and Crane Chains*—W. J. Merten, Westinghouse Electric and Manufacturing Co., East Pittsburgh.

11:25—12:00 A. M.—*High Carbon, High Chromium Steels*—J. P. Gill, Vanadium Alloys Steel Co., Latrobe, Pa.

12:00—12:30 P. M.—*Steel Failures in Aircraft*—F. T. Sisco, Wright Field, Dayton, Ohio.

On the Equilibrium Diagram of the Iron-Molybdenum System—Takeshi Takei and Takejiro Murakami, Tohoku Imperial University, Sendai, Japan. (By title)

FRIDAY, OCTOBER 12

Afternoon Session

Meeting in Assembly Room, Commercial Museum
W. Trinks, Chairman

2:30—3:00 P. M.—*Effect of Furnace Atmospheres on Steels*—R. G. Guthrie, Peoples Gas Light and Coke Co., Chicago.

3:00—3:30 P. M.—*Progress Made in the Use of Electric Furnaces for Heat Treating*—A. N. Otis, General Electric Company, Schenectady, N. Y.

3:30—4:00 P. M.—*A New Method for Heat Treating High Speed Steel*—Horace C. Knerr, Consulting Metallurgist, Philadelphia.

4:00—4:30 P. M.—*Heating High Speed Steel to 2400 Degrees Fahr. in Molten Lead*—Wilbur C. Searle, Leland Gifford Company, Putnam, Conn.

OUTLINE OF PLANT INSPECTION

Tuesday, October 9

Midvale Company
Riehle Brothers Testing Machine Company
Curtis Publishing Company

Wednesday, October 10

Leeds and Northrup Company
Temple University
Westinghouse Electric and Manufacturing Company

Thursday, October 11

Victor Talking Machine Company
Autocar Company
Brown Instrument Company

Friday, October 12

Tinius Olsen Testing Machine Company
U. S. Navy Yard

No Assigned Date

William Sellers and Company, Inc.
Bethlehem Steel Company, Inc.
Ajax Electrothermic Corporation
Carpenter Steel Company

Ladies' Entertainment

All ladies attending the Philadelphia Conventions and exposition will have their entertainment as a single group. This includes the ladies of the three national societies meeting in Philadelphia the week of October 8th. The registration of the ladies of the American Society for Steel Treating and the Institute of Metals will be at the Benjamin Franklin Hotel. Registration for ladies of the American Welding Society will be at the Bellevue-Stratford Hotel.

The following program of entertainment has been scheduled.

Monday, October 8

12:30 P. M.—Luncheon at Benjamin Franklin Hotel, Betsy Ross Room, followed by automobile ride. Admission by ticket only.

Tuesday, October 9

2:00 P. M.—Bridge party, Benjamin Franklin Hotel, Betsy Ross Room, or Shopping Tour.

Wednesday, October 10

1:30 P. M.—Automobile Tour to Valley Forge. Admission by ticket only.

Thursday, October 11

2:00 P. M.—Sight-Seeing Tour, followed by Tea at the Benjamin Franklin Hotel. Admission by ticket only. (Tea at 4:00 P. M. in the Besty Ross Room.)

Golf

Golf privileges of several clubs are available. Complete information may be secured at the Registration Desk at the Convention Hall, where privilege cards will be issued.

Daily Newspaper

The *Daily Metal Trade*, published in Cleveland by the Penton Publishing Company, will again issue a special edition during the week of the National

Metal Exposition, as announced in the September issue of TRANSACTIONS. Copies will be available at the various hotels and at the exposition, as well as being mailed to the home addresses of the members of the American Society for Steel Treating.

AMERICAN WELDING SOCIETY

The program committee of the American Welding Society have arranged an especially fine program for the various technical sessions to be held at the Bellevue-Stratford Hotel. Papers on subjects of current interest and setting forth new ideas and adaptations of the welding industry are scheduled for presentation and these meetings should prove instructive and valuable to the members of the society and their guests.

The Welding and Cutting Exposition held under the auspices of the American Welding Society, and in cooperation with the National Metal Exposition, will afford those in attendance an opportunity to observe the latest and best equipment and development in this field. Approximately 10,000 square feet of exhibit space will be occupied by the exhibitors of the American Welding Society.

INSTITUTE OF METALS

The Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers will hold their annual fall meeting at Philadelphia, the week of October 8.

Chairman Stanislaus Skowronski and his committeemen have arranged an excellent program of technical sessions and there will be one joint session of the Institute of Metals and the American Society for Steel Treating, to be held at the Commercial Museum on Wednesday afternoon at 2:30 P. M.

The entertainment of both ladies and men will be in cooperation with the other societies.

The annual Institute dinner will be held at the Benjamin Franklin Hotel on Wednesday evening.

DROP FORGE SUPPLY ASSOCIATION DINNER

The Drop Forge Supply Association, Charles Harman, President, and A. L. Wurster, Secretary, are making arrangements for their annual dinner to be held on Wednesday evening, October 10, at Bookbinders, Second and Walnuts Streets.

Complete information relative to the dinner may be obtained from Mr. Wurster, at the booth of the Heppenstall Forge and Knife Company, Booth No. 195, or by addressing the headquarters at 1020 Drexel Building, Philadelphia.

PROGRAM OF THE ANNUAL FALL MEETING OF THE AMERICAN WELDING SOCIETY

Philadelphia, October 8 to 12, 1928.
Headquarters—Bellevue-Stratford Hotel.

MONDAY, OCTOBER 8

Morning Session

10:00 A. M.—Registration for members and guests, Bellevue-Stratford Hotel.

12:00 A. M.—Registration for members and guests, Commercial Museum. A registration fee of $1.00 will be charged members and their male guests. Members and their guests are requested to register as admission to Commercial Museum and some of the social events will be by badge only.

Afternoon Session

2:00 P. M.—Meeting of Board of Directors, American Welding Society, Bellevue-Stratford Hotel, Assembly Room.

TUESDAY, OCTOBER 9

Morning Session

10:00 A. M.—Business Session, Bellevue-Stratford Hotel.
This will be in the nature of a few introductory remarks by President Llewellyn, and transaction of any formal business or introduction of local celebrities.
Technical Session—Bellevue-Stratford Hotel—
F. T. Llewellyn, President, presiding.

10:30 A. M.—*Welding in Heating, Ventilating and Plumbing Industry*—R. A. Jack, Domestic Engineering.
Testing Joints for Aircraft Structure Prepared under Procedure Specifications—H. L. Whittemore, Bureau of Standards, Washington, D. C., and H. H. Moss, Linde Air Products Company.

Afternoon Session

2:00 P. M.—Technical Session, Commercial Museum, Lecture Room—F. M. Farmer, Past President, presiding.
Welds at Elevated Temperatures—Professor C. Moser, Leland Stanford University.
Formula for Computing Design Stresses for Pressure Vessels—S. W. Miller, Union Carbide and Carbon Research Laboratories.

Evening Program

9:30 P. M.—Grand Ball, Benjamin Franklin Hotel Ballroom. Admission by ticket only.

WEDNESDAY, OCTOBER 10

Morning Session

10:00 A. M—Technical Session, Bellevue-Stratford Hotel—R. D. Thomas, Chairman Philadelphia Section, presiding.

Running a Successful Job Welding Plant—J. S. Oechsle, President, Mataweld, Inc.

Welding in the Automobile Industry—J. W. Meadowcroft, Assistant Works Manager, Edward G. Budd Mfg. Co.

Afternoon Session

2:00 P. M.—Inspection Trip. Inspection trips have been arranged to places of interest to members in Philadelphia. Tentative arrangements have been made for visiting the General Electric welded building, the plant of the E. G. Budd Mfg. Co., and an aeroplane plant.

THURSDAY, OCTOBER 11

Morning Session

10:00 A. M.—Meeting of the Joint Pressure Vessel Committee—Bellevue-Stratford Hotel—E. W. Ewertz, Chairman, presiding.

Afternoon Session

2:00 P. M.—Technical Session—Commercial Museum, Assembly Room, A. G. Oehler, Past President, presiding.

Design of Welded Structures—F. P. McKibben, Consulting Engineer, General Electric Company.

Erecting a Building by Welding—J. F. Lincoln, Lincoln Electric Co.

Oxyacetylene Cutting in the Structural Field—H. E. Rockefeller, Linde Air Products Co.

Evening Program

6:30 P. M.—Annual Banquet and Dance, Bellevue-Stratford Hotel.

FRIDAY, OCTOBER 12

Morning Session

10:00 A. M.—Technical Session—Bellevue-Stratford Hotel, H. L. Whittemore, presiding.

Special film on *Studies of the Metal Arc*—Dr. Karl Bung, German Engineer.

Design of Machinery Parts by Use of Welding of Steel Shapes—Messrs. Hague, Marthens and Brinton, Westinghouse Electric and Mfg. Co.

Afternoon Session

2:00 P. M.—Meeting of American Bureau of Welding, Bellevue-Stratford Hotel—Director C. A. Adams, presiding.

Evening Session

8:00 P. M.—Meeting of Structural Steel Welding Committee, Bellevue-Stratford Hotel, J. H. Edwards, Chairman, presiding.

TECHNICAL PAPERS PROGRAM OF THE INSTITUTE OF METALS

TUESDAY, OCTOBER 9

Morning Session—Benjamin Franklin Hotel

R. S. Dean, Chairman
P. D. Merica, Vice-Chairman

10:00 A. M.—*Less Common Elements in the Electrical Industry*—T. S. Fuller.
Gases in Casting Copper—O. W. Ellis.
Diffusion of Zinc Into Copper—S. L. Hoyt.
Constitution of the Copper Silicon System—C. S. Smith.

WEDNESDAY, OCTOBER 10

Afternoon Session

(Joint session with the American Society for Steel Treating—Assembly Room, Commercial Museum)

Dr. Zay Jeffries, Chairman
Charles McKnight, Vice-Chairman

2:30 P. M.—*Notes on Smoothing and Etching*—H. B. Pulsifer.
Further Observations on the Microstructure of Martensite—F. F. Lucas.
Treatment and Structure of Magnesium Alloys—J. A. Gann.
Neumann Bands in Ferrite—C. H. Mathewson.
A Study of the Constitution of High Manganese Steels—V. N. Krivobok.

WEDNESDAY, OCTOBER 10

Evening Meeting—6:30 P. M.

Institute of Metals Division Dinner—Benjamin Franklin Hotel
Chromium Alloys—Dr. F. M. Becket, Vice-President Union Carbide Company.

THURSDAY, OCTOBER 11

Morning Session—Benjamin Franklin Hotel

E. H. Dix, Jr., Chairman
Sam Tour, Vice-Chairman

10:00 A. M.—*Effect of Cold Rolling and Heat Treatment Upon the Physical Properties of Britannia Metal*—B. Egeberg and H. B. Smith.
Stability of Aluminum and Magnesium Casting Alloys—A. J. Lyon.
Equilibrium Relations in Aluminum, Magnesium and Aluminum-Magnesium-Silicide Alloys of High Purity—F. Keller and and E. H. Dix.
Permanent Mold Aluminum Alloy Pistons.
High Strength Gold Alloys—E. M. Wise.

THOSE WHO WILL EXHIBIT IN COMMERCIAL MUSEUM

The following is a complete list of exhibitors as of September 20 of those companies and individuals who will have exhibits at the National Metal Exposition.

A

Abrasive Company	Philadelphia
Acme Electric Welder Company	Philadelphia
Air Reduction Sales Company	New York City
Ajax Electrothermic Corporation	Trenton, N. J.

American Brass Company	Waterbury, Conn.
Allen Steel Company, Edgar	New York City
American Car and Foundry Company	New York City
American Gas Association	New York City
American Gas Furnace Company	Elizabeth, N. J.
American Machinist	New York City
American Manganese Bronze Company	Philadelphia
American Metal Market	New York City
American Metallurgical Corporation	Boston
American Steel and Wire Company	Chicago
Ampco Twist Drill Company	Jackson, Mich.
Andresen and Associates, Inc., F. C.	Pittsburgh
Armstrong-Blum Manufacturing Company	Chicago
Armstrong Brothers Tool Company	Chicago
Armstrong Cork and Insulation Company	Pittsburgh
Atkins and Company, E. C.	Indianapolis
Atlantic Steel Castings Company	Chester, Pa.
Atlas Steel Corporation	Dunkirk, N. Y.
Automatic Nut-Thread Corporation	Philadelphia
Automatic Temperature Control Company	Philadelphia
Automotive Industries	New York City

B

Barnes Company, Inc., W. O.	Detroit
Bastian Blessing Company	Chicago
Bausch and Lomb Optical Company	Rochester, N. Y.
Bell and Gossett Company	Chicago
Bellevue Industrial Furnace Company	Detroit
Bellis Heat Treating Company	Branford, Conn.
Bethlehem Steel Company	Bethlehem, Pa.
Biax Flexible Shaft Company, Inc.	New York City
Blakeslee and Company, G. S.	Cicero, Ill.
Bond Company, Charles	Philadelphia
Botfield Refractories Company	Philadelphia
Brinton Company, H.	Philadelphia
Bristol Company	Waterbury, Conn.
Brown and Company, D. P.	Philadelphia
Brown Instrument Company	Philadelphia
Brown Lynch Scott Company	Monmouth, Ill.
Budd Mfg. Co., Edward G.	Philadelphia

C

Campbell, Inc., Andrew C.	Bridgeport, Conn.
Carborundum Company	Perth Amboy, N. J.
Carborundum Company	Niagara Falls, N. Y.
Carpenter Steel Company	Reading, Pa.
Case Hardening Service Company	Cleveland
Celite Products Company	Los Angeles, Calif.

Central Alloy Steel Corporation	Massillon, Ohio
Char Products Company	Indianapolis
Chicago Pneumatic Tool Company	Philadelphia
Chicago Steel and Wire Company	Chicago
Chicago Steel Foundry Company	Chicago
Chrobaltic Tool Company	Detroit
Cleveland Twist Drill Company	Cleveland
Climax Molybdenum Company	New York City
Clipper Belt Lacer Company	Grand Rapids, Mich.
Coats Machine Tool Company, Inc.	New York City
Colonial Steel Company	Philadelphia
Colonial Tool Company	Detroit
Cooper Hewitt Electric Company	Hoboken, N. J.
Crucible Steel Casting Company	Lansdowne, Pa.
Crucible Steel Company of America	New York City
Cyclops Steel Company	Titusville, Pa.

D

Danly Machine Specialties Inc.	Chicago
Darwin and Milner, Inc.	Cleveland
Dearborn Chemical Company	Chicago
Deemer Steel Casting	New Castle, Delaware
Disston and Sons, Inc., Henry	Philadelphia
Dodge Steel Company	Philadelphia
Donner Steel Company	Buffalo, N. Y.
Driver-Harris Company	Harrison, N. J.
Duriron Company	Dayton, Ohio

E

Eastman Kodak Company	Rochester, N. Y.
Eclipse Fuel Engineering Company	Rockford, Ill.
Electric Arc Cutting and Welding Company	Newark, N. J.
Electric Furnace Company	Salem, Ohio
Electric Steel Founders Research Group	Chicago
Electro Alloys Company	Elyria, Ohio
Electro Refractories Company	Buffalo, N. Y.
Elkon, Inc.	New York City
Emery-Tatnall Company	Philadelphia
Empire Steel Casting Company	Reading, Pa.
Endicott Forging and Manufacturing Company	Endicott, N. Y.

F

Falls Electric Furnace Corp.	Buffalo, N. Y.
Federal Machine & Welder Company	Warren, Ohio
Ferner Company, R. Y.	Washington, D. C.
Finkl and Sons Company, A.	Chicago
Firth-Sterling Steel Company	McKeesport, Pa.
Ford Company, J. B.	Wyandotte, Mich.
Frew Machine Company	Philadelphia
Fusion Welding Corporation	Chicago

G

Gairing Tool Company	Detroit
Gathmann Engineering Company	Baltimore, Md.
General Alloys Company	Boston, Mass.
General Electric Company	Schenectady, N. Y.
General Insulating & Mfg. Co.	Alexandria, Ind.
Gibb Welding Machines Company	Bay City, Mich.
Giddings and Lewis Machine Tool Company	Fond-du-Lac, Wis.
Globar Corporation	Niagara Falls, N. Y.
Goodell-Pratt Company	Greenfield, Mass.
Goss and De Leeuw Machine Company	New Britian, Conn.
Gray Iron Institute	Cleveland

H

Hagan Company, George J.	Pittsburgh
Halcomb Steel Company	Syracuse N. Y.
Harrington Company	Philadelphia
Hartford Machine Screw Company	Hartford, Conn.
Hayes, C. I.	Providence, R. I.
Haynes-Stellite Company	Kokomo, Ind.
Heintz Manufacturing Company	Philadelphia
Heppenstall Forge and Knife Company	Pittsburgh
Herron Company, James A.	Cleveland
Hevi Duty Electric Company	Milwaukee
Hisey Wolf Machine Company	Cincinnati
Holcroft and Company	Detroit
Hoskins Manufacturing Company	Detroit
Houghton and Company, E. F.	Philadelphia
Hydraulic Tool Works	Philadelphia

I

Ideal Industrial Machinery	Cincinnati
Illingworth Steel Co., John	Philadelphia
Illinois Steel Company	Chicago
Illinois Tool Works	Chicago
International Nickel Company	New York City
Iron Age	New York City

J

Jessop Steel Company	Washington, Pa.
Jessop and Sons, Inc., William	New York City
Jones and Laughlin Steel Corporation	Pittsburgh
Jones Machine Tool Works	Philadelphia

K

K-G Welding and Cutting Company	New York City
Keller Mechanical Engineering Corporation	Brooklyn, N. Y.
Kelley Company, J. W.	Cleveland
Kelly Reamer Company	Cleveland
Kemp Manufacturing Company, C. M.	Baltimore, Md.

KENWORTHY, INC., C. F.	Waterbury, Conn.
KEYSTONE DRAWN STEEL COMPANY	Spring City, Pa.
KEYSTONE LUBRICATING COMPANY	Philadelphia
KINITE CORPORATION	Milwaukee

L

LAVA CRUCIBLE COMPANY OF PITTSBURGH	Pittsburgh
LAVINO AND COMPANY, E. J.	Philadelphia
LEEDS AND NORTHRUP COMPANY	Philadelphia
LEITZ, INC., E.	New York City
LINCOLN ELECTRIC COMPANY	Cleveland
LIND AIR PRODUCTS COMPANY	New York City

M

MAHR MANUFACTURING COMPANY	Minneapolis, Minn.
MARBURG BROTHERS, INC.	New York City
MCCANN-HARRISON CORPORATION	Cleveland
MCGILL METAL COMPANY	Valparaiso, Ind.
METAL AND THERMIT CORPORATION	New York City
MICHIGAN STEEL CASTING COMPANY	Detroit
MICHIGAN TOOL COMPANY	Detroit
MIDVALE COMPANY	Nicetown, Philadelphia
MILBURN COMPANY, ALEXANDER	Baltimore
MILL AND FACTORY ILLUSTRATED	New York City
MILNE AND COMPANY, A.	New York City
MILWAUKEE DIE CASTING COMPANY	Milwaukee
MOLYBDENUM CORPORATION OF AMERICA	Pittsburgh
MORGAN STEEL COMPANY	Philadelphia
MORRIS WHEELER & CO., INC.	Philadelphia
MORSE TWIST DRILL AND MACHINE COMPANY	New Bedford, Mass.
MUELLER BRASS COMPANY	Port Huron, Mich.

N

NATIONAL ELECTRIC LIGHT ASSOCIATION	New York City
NATIONAL TWIST DRILL AND TOOL COMPANY	Detroit
NEW DEPARTURE MANUFACTURING COMPANY	Bristol, Conn.
NORTON COMPANY	Worcester, Mass.
NUTTALL CO., R. D.	Pittsburgh

O

OLSEN TESTING MACHINE COMPANY TINIUS	Philadelphia

P

PAGE STEEL AND WIRE COMPANY	Bridgeport, Conn.
PEERLESS MACHINE COMPANY	Racine, Wis.
PENNSYLVANIA ELECTRIC STEEL CASTING COMPANY	Hamburg, Pa.
PEOPLES GAS LIGHT AND COKE COMPANY	Chicago
PENTON PUBLISHING COMPANY	Cleveland
PITTSBURGH INSTRUMENT AND MACHINE COMPANY	Pittsburgh
PORTER-CABLE MACHINE COMPANY	Syracuse, N. Y.

Potts and Company, Horace T.	Philadelphia
Production Machine Company	Greenfield, Mass.
Pyrometer Instrument Co.	New York City

R

Riehle Brothers Testing Machine Company	Philadelphia
Reines, Charles	Brooklyn, N. Y.
Reintjes Company, Geo. P.	Kansas City, Mo.
Reeves Pulley Company	Columbus, Ind.
Riverside Steel Casting Company	Newark, New Jersey
Rockwell Company, Stanley P.	Hartford, Conn.
Rockwell Company, W. S.	New York City
Roebling's Sons Company, John A.	Trenton, N. J.
Roessler and Hasslacher Chemical Company	New York City
Rotor Air Tool Company	Cleveland

S

Scherr Company, Inc., George	New York City
Sentry Company	Taunton, Mass.
Shenango-Penn Mold Company	Dover, Ohio
Shore Instrument and Manufacturing Company	Jamaica, N. Y.
Siewek Tool and Die Company	Detroit
Simonds Saw and Steel Company	Fitchburg, Mass.
Sleeper and Hartley, Inc.	Worcester, Mass.
Smith and Sons, Inc., David H.	Brooklyn, N. Y.
Smith Welding Equipment Eastern Corporation	Philadelphia
Southern Manganese Steel Company	St. Louis, Mo.
Spencer Turbine Company	Hartford, Conn.
Standard Alloy Company, Inc.	Cleveland
Standard Tool Company	Cleveland
Starrett Company, L. S.	Athol, Mass.
Steel Castings Development Bureau	Philadelphia
Steel City Testing Laboratory	Detroit
Steel Publications, Inc.	Pittsburgh
Steinmetz Electric Furnace Company	Philadelphia
Sullivan Machinery Company	Chicago
Surface Combustion Company	Toledo, Ohio
Swind Machinery Company	Philadelphia

T

Temple University	Philadelphia
Thermist Company, Inc.	Phillipsburg, N. J.
Thomas and Company, R. D.	Philadelphia
Thwing Instrument Company	Philadelphia
Timken Roller Bearing Company	Canton, Ohio
Timken Steel and Tube Company	Canton, Ohio
Torchweld Equipment Company	Chicago
Transportation Engineering Corporation	Brooklyn, N. Y.
Treadwell Engineering Company	Easton, Pa

TRENT COMPANY, HAROLD E.	Philadelphia
TUTHILL PUMP COMPANY	Chicago
U	
UNA WELDING AND BONDING COMPANY	Cleveland
UNION MANUFACTURING COMPANY	New Britain, Conn.
UNISHEAR COMPANY, INC.	New York City
UNIVERSAL STEEL COMPANY	Bridgeville, Pa.
V	
VANADIUM ALLOYS STEEL COMPANY	Latrobe, Pa.
VANADIUM CORPORATION OF AMERICA	New York City
VAN DORN ELECTRIC TOOL COMPANY	Cleveland
VULCAN CRUCIBLE STEEL COMPANY	Aliquippa, Pa.
W	
WELDING ENGINEER	Chicago
WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY	East Pittsburgh, Pa.
WHEELING MOLD AND FOUNDRY COMPANY	Wheeling, W. Va.
WHEELOCK LOVEJOY AND COMPANY, INC.	Cambridge, Mass.
WHITNEY METAL TOOL COMPANY	Rockford, Ill.
WICKWIRE SPENCER STEEL COMPANY	New York City
WIEDEMANN MACHINE COMPANY	Philadelphia
WIEGAND COMPANY, EDWIN L.	Pittsburgh
WILLIAMS AND COMPANY, J. H.	Buffalo, N. Y.
WILSON-MAEULEN COMPANY	New York City
WILSON WELDER AND METALS COMPANY, INC.	Hoboken, N. J.
Y	
YOUNG BROTHERS COMPANY	Detroit
Z	
ZIV STEEL AND WIRE COMPANY	Chicago

ENGINEERING EXTENSION LECTURES

John F. Keller, of Purdue University, is again with the Society, from August through December of this year. He is giving his six-lecture course of "Steel and Its Treatment" to industrial groups in the communities of Bridgeport, New Haven, Hartford, Springfield and Worcester.

A second series of lectures will be given between November 12 and December 21, the three weeks prior to November 12 being devoted to organizing this series of lectures. The cities to be included in the second series of lectures have not been definitely determined, but will be decided upon in the near future.

Through the hearty cooperation of the chapters of the A. S. S. T. in each community, the interest response has been more than gratifying. The total enrollment is 65 per cent higher than that of the first series of lectures held a year ago this time.

The enrollment is as follows: Bridgeport 59, New Haven 72, Hartford 187, Springfield 209, and Worcester 86; a total of 613.

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of August there were 76 new and reinstated members, while 90 were lost through arrears, resignations and deaths, leaving a net loss for the month of 14 members. The total membership of the society on September 1, 1928, was 4844.

Membership standing of the society as of September 1, 1928, is as follows:

GROUP I		GROUP II		GROUP III	
1. Detroit	476	1. Los Angeles	161	1. New Haven	97
2. Chicago	435	2. Hartford	139	2. Worcester	73
3. Pittsburgh	356	3. Golden Gate	122	3. Washington	71
4. New York	315	4. Lehigh Valley	118	4. Tri-City	68
5. Philadelphia	314	5. Milwaukee	114	5. Rockford	61
6. Cleveland	293	6. St. Louis	104	6. Providence	58
7. Boston	250	7. Cincinnati	104	7. Rochester	56
		8. Dayton	94	8. Southern Tier	53
		9. Indianapolis	93	9. Toronto	52
		10. Canton-Mass.	84	10. Columbus	48
		11. Syracuse	83	11. Schenectady	44
		12. Buffalo	79	12. Springfield	39
		13. Montreal	68	13. Fort Wayne	27
		14. North-West	57	14. Notre Dame	24

GROUP I—This group has had its first change in a number of months when New York with a gain of 1 advanced from fifth to fourth position passing Philadelphia.

GROUP II—Los Angeles still heads this group with 161. This chapter has had a very beneficial increase during the past year. Hartford with 139 holds incessantly on second place. Cincinnati with a gain of 1 goes into a tie with St. Louis for sixth place, while Dayton advanced from ninth to eighth position, passing Indianapolis. Canton-Massillon performed a similar feat and advanced from eleventh to tenth place, passing Syracuse.

GROUP III—New Haven is still in position one with a lead of 24 members. The only change in this group was that Toronto with a loss of 2 went from eighth to ninth place, permitting Southern Tier to advance to position eight.

Items of Interest

AT a recent meeting of the board of directors of the Vanadium-Alloys Steel Company of Latrobe, Pennsylvania, a proposal which later received favorable consideration was made to the directors of the Colonial Steel Company of Pittsburgh, Pennsylvania, whereby shares of stock of the Colonial Steel Company are to be exchanged for shares of stock of the Vanadium-Alloys Steel Company.

A meeting of stockholders of the Vanadium-Alloys Steel Company has been called for October 30 to approve the action of the directors.

No changes in the management of the Colonial Steel Company are contemplated for the present, except that the sales of the products of the two companies will be co-ordinated.

George P. Rhodes, T. Howe Childs and S. Clarke Reed will be the representatives of the Colonial Steel Company on the board of directors of the Vanadium-Alloys Steel Company.

The Gunite Corp., Rockford, Ill., has issued a booklet describing "Gunite", a new pearlitic steel which it is said is obtained by a special process. The product is for use where wear and rigidity are principal considerations.

The Linde Air Products Co., 30 E. 42nd St., New York, have recently opened a new district sales office at 48 W. McLemore Ave., Memphis, Tenn.

The Ohio Steel Foundry Co., Lima, O., has recently awarded a contract for a new foundry unit for the manufacture of locomotive and other heavy castings.

The American Steel Abrasive Co., Galion, Ohio, has recently issued a booklet giving information on steel abrasives and illustrating a method used to test steel shot to determine if the hardness is up to the standard required.

A 16-page folder describing some of the applications of the electric industrial heating equipment which it manufactures has been issued by the General Electric Co., Schenectady, N. Y.

Fusion Welding Corp., 103 St., and Torrence Ave., Chicago, has available bulletin 128 entitled, "The Influence of Carbon in Steel Welding Rods."

Mineral resources of the United States 1925 published by the United States Bureau of Mines may be obtained from the Government Printing Office, Washington. Part I—Metals, contains 768 pages, price $1.25. Part II—Non-Metals, contains 615 pages, price $1.00.

Various pieces of equipment used in oxyacetylene cutting and welding are described in a catalog recently issued by the Oxweld Acetylene Co.,

Carbide and Carbon Bldg., New York. This equipment includes blow pipes, cutting nozzles, portable welding and cutting units and a low pressure type acetylene generator.

A rivet forge especially adapted for use in railroad car repair work is described in a bulletin issued by the Mahr. Mfg. Co., Minneapolis.

The International Acetylene Association, 30 East 42nd St., New York, has issued a bulletin pointing out the superiority of acetylene as fuel gas for cutting as compared to city gas, based upon laboratory and shop studies.

An illustrated 31-page bulletin entitled, "Industrial Gas Heat," may be obtained by addressing a request to American Gas Association, 420 Lexington Ave., New York.

The Pittsburgh Instrument and Machine Co. announces that it is manufacturing a precision hardness testing machine of the Brinell type. It is stated that the accuracy of the Brinell hardness test is governed by the accuracy of the applied load, rate of application, and the time the load is applied. Also that a system of weights and levers is the most accurate device for applying a fixed load and that this machine utilizes a system of weights and levers to give the applied load.

P. S. Menough has recently joined the organization of the Duraloy Co., of Pittsburgh, as assistant to the president. Mr. Menough was for nine years chief engineer with the Eastern Malleable Iron Co., of Bridgeport, Conn.

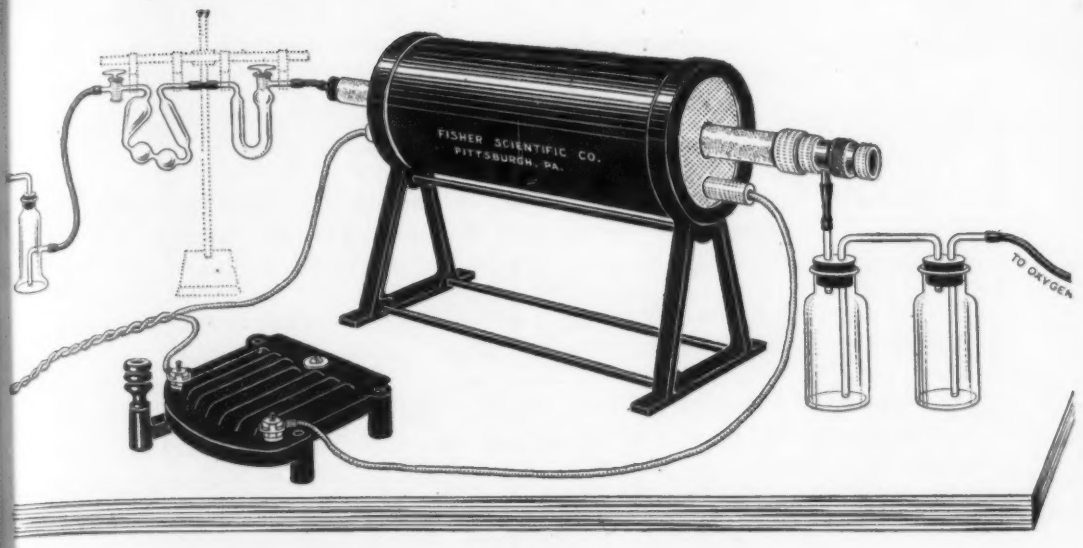
Thomas W. Hardy, formerly metallurgist with the Timken Roller Bearing Co., Canton, Ohio, has accepted a position as metallurgical engineer in the division of ore dressing and metallurgy, mines branch, Department of Mines, Ottawa, Ontario, Canada.

Botfield Refractories Co., Philadelphia, manufacturers of Adamant Firebrick Cement, Adamant-Adachrome and the Adamant Gun, announces the appointment of W. E. Tierney as its representative in the South and Southwest. Mr. Tierney is a mechanical engineer and a graduate of Tulane University. Mr. Tierney's headquarters will be in New Orleans.

The second edition of the Standards Yearbook 1928 has been issued by the United States department of commerce, this may be obtained from the superintendent of documents, United States government printing office, Washington, for $1.00.

It is stated that the Stout Metal Airplane division of the Ford Motor Co., Dearborn, Mich., has increased production in its standard tri-motored, all-metal airplane to two planes a week.

(Continued on Page 36 Adv. Sec.)



STETSER-NORTON COMBUSTION TRAIN (FSCo. 7-445)

A train which is often used exactly as illustrated. We can, however, supply it with any desired modifications.

Fisher Combustion Apparatus

Pittsburgh, which has been recognized as the heart of the steel industry, has been a fertile field in the development of methods and apparatus for the combustion work of the iron and steel chemist. Many specialized items of apparatus have been developed in our own instrument shops. Among them are the following:

FISHER Breech Connector,

For combustion tubes; enables boats to be inserted without disconnecting the apparatus. The price is $15.00 and the description is found on page 251 of the Fisher Catalogue.

FISHER Heavy Duty Combustion Boat,

Made of carbon-free nickel in a convenient shape. Will not break in heating, cooling or handling. The price is $6.00 per dozen and the description is found on page 254 of the Fisher Catalogue.

FISHER Combustion Tube Rake,

Of chromel; facilitates inserting and withdrawing boats, also cleaning tube. The price is $2.75 each and the description is found on page 252 of the Fisher Catalogue.

FISHER Combustion Boat Lining (SINDERITE),

Prevents sputtering of sample and saves boats and tubes. The price is $.95 per pound and the description is found on page 256 of the Fisher Catalogue.

For selection of combustion apparatus, see Fisher Catalogue, pages 244 to 256.

Fisher Scientific Company

Laboratory Apparatus and Reagents for Chemistry, Metallurgy, Biology

PITTSBURGH · PENNSYLVANIA

IN CANADA, FISHER SCIENTIFIC CO. Ltd., 472 McGILL STREET, MONTREAL

"Fuel Briquets in 1927," a phamphlet by F. G. Tryon and J. M. Corse, has been issued by the United States Bureau of Mines. Detailed statistics of the American Industry and world production are given.

Bulletin No. 1011 showing model L industrial electric pot furnaces designed for temperatures up to 1600 degrees Fahr. has been issued by the Sentry Co., Taunton, Mass.

The recently organized Gray Iron Institute has established permanent headquarters in the Terminal Tower Bldg., Cleveland.

A series of bulletins is being published by the Whiting Corp., Harvey, Ill., containing technical articles on cast iron and its manufacture. These bulletins are written by Dr. Edward E. Marbaker of the Mellon Institute of Industrial Research, Pittsburgh.

The nation's business during the first half of 1928 exhibited a continuance of the activity and program which has now lasted for a sufficient number of years to mark a general stability unparalleled in the economic history of the United States or any other important industrial country. This conclusion is based upon business indicators compiled from reports of governmental and private statistical organizations for the Commerce Department's semi-annual review of economic conditions. The Department also points out that the indices show that the only important industries which are lagging behind the national pace are textiles in the manufacturing group, and agriculture, and coal among the basic raw material industries.

The Sheet Aluminum Corp., Jackson, Mich., has recently placed on the market a balanced aluminum alloy that is said to be fundamentally new in composition and in application to a wide variety of products, for many of which aluminum has never before been practicable. It is claimed for this alloy that it combines lightness and strength to a greater degree than any other workable product of its kind ever developed on a commercial basis.

The new aluminum alloy is known by the registered name of Hyb-Lum. Research and experimental work on the alloy was done by Victor N. Hybinette, Jr., with the advice and assistance of his father.

Walter M. Saunders and Frederick H. Franklin announce the dissolution of the partnership of Saunders and Franklin, analytical and consulting chemists, 184 Whittier Ave., Providence, R. I.

Mr. Saunders will continue in business as Walter M. Saunders, 184 Whittier Ave., Providence, R. I., and Mr. Franklin will continue in business as the Franklin Laboratory, 589 Atwells Ave., Providence, R. I.

"Spiegeleisen" is the title of a booklet recently issued by the New Jersey Zinc Co. This booklet may be obtained by addressing a request to the New Jersey Zinc Sales Co., 169 Front St., New York.

Wallace G. Imhoff has opened an office at 401 Highland Bldg., Pittsburgh, as a consulting metallurgical engineer in pickling and galvanizing. Mr. Imhoff's practical experience in the galvanizing field dates back over a period of fifteen years.

(Continued on Page 38 Adv. Sec.)

SIMONDS
QUALITY UNIFORMITY

FOR THOSE WHO DEMAND THE BEST
IN THEIR FINISHED PRODUCT

SIMONDS STEEL

TOOL STEEL
MAGNET STEEL
SPECIAL ANALYSIS STEEL

SHEETS
BARS

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SIMONDS STEEL MILLS

LOCKPORT, NEW YORK

Charles E. Margerum has been reinstated by President Coolidge as a material engineer in the naval gun factory, Washington Navy Yard, without regard to the time limit on reinstatement under the civil service rules. Mr. Margerum was employed in the field service of the Navy Department from August, 1917, until November, 1922, and the Secretary of the Navy recommended his reinstatement in the interest of the Government "as he had rendered particularly valuable and efficient service."

The Uehling Instrument Co., Paterson, N. J., is manufacturing an electrically operated CO_2 recorder and indicator by means of which it is stated that the correct air supply may be maintained, irrespective of changing load conditions.

A folder on plastic refractories for use as furnace linings has been issued by the Ironton Fire Brick Co., Ironton, Ohio.

E. F. Houghton & Co., Philadelphia, is distributing a 142-page book entitled, "Liquid Baths for Heat Treatment of Steel." The book is said to be a compilation of the best known practices on the use of liquid baths for steel.

The American Refractories Institute will hold its fall meeting October 24, 1928, at the William Penn Hotel, Pittsburgh. Headquarters of the institute are at 2202 Oliver Bldg., Pittsburgh.

The Armstrong Insulating Co., Pittsburgh, reports that it has developed a brick to fill the need for an efficient insulating material for equipment operating at high temperature. It is stated that the brick will withstand 2500 degrees Fahr. without shrinking, calcining or spalling, and can be successfully used where insulation has heretofore been considered impracticable.

H. H. Harris, president of the General Alloys Company, is offering two rather unusual attendance prizes for those who attend the Convention. The U. S. S. Frigate Constitution, known as "Old Ironsides," is being repaired and reconditioned. A block and gavel made from timbers of this historic ship will be awarded to the chapter of the American Society for Steel Treating within 500 miles of Philadelphia having the largest number of members in attendance. A second block and gavel will be awarded to the chapter located at a greater distance than 500 miles of Philadelphia, and having the largest attendance.

Some interesting facts about "Old Ironsides" are as follows: It is one of the first three vessels built by the United States, and was launched in Hartt's shipyard, Boston, in October 1797. In 1798 the Constitution was active in suppressing French pirateers and during the war of 1812 she defeated the Guerriere, Java, Picton, Cyane, Levant and captured many other vessels, turning the tide of defeat into victory, and averting the secession of the New England States from the Union and establishing the Declaration of Independence as a fact.

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